The Sense of Agency in Hypnosis and Meditation

Peter J. I. Lush

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UNIVERSITY OF SUSSEX

PETER JAMES I'ANSON LUSH, PhD PSYCHOLOGY

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SUMMARY

The sense of agency is the experience of being the initiator of our intentional actions and their outcomes. According to higher order thought theory, a representation becomes conscious when there is a higher order state about it. Thus conscious experience, including that of intentions, is metacognitive. The experience of involuntariness characteristic of hypnotic responding may be attributable to the formation and maintenance of inaccurate metacognitive higher order states of intending. Conversely, the practice of Buddhist mindfulness meditation may develop accurate metacognition, including higher order states of intending. Highly hypnotisable people and mindfulness meditators may therefore occupy two ends of a spectrum of metacognitive ability with regard to unconscious intentions. The presented research investigated predicted trait differences in cognitive tasks which directly or indirectly reflect metacognition of intentions: the timing of an experience of an intention to move and the compressed time interval between a voluntary action and its outcome, known as intentional binding. As an implicit measure of sense of agency, intentional binding was also employed to investigate the veridicality of reports of the experience of involuntariness in hypnotic responding. Additionally, while hypnosis presents a unique opportunity to investigate reliable changes in agentic experience, existing hypnosis screening instruments are time consuming and present a barrier to wider adoption of hypnosis as an instrument for studying consciousness. Here a revised, time-efficient hypnosis screening procedure (the SWASH) is presented.

Consistent with predictions, highly hypnotisable groups reported later awareness of motor intentions than less hypnotisable groups and meditators earlier awareness than non-meditators. In an intentional binding task, high hypnotisables showed less binding of an action-outcome toward an action (outcome binding) than low hypnotisables and meditators more outcome binding than non-meditators. Outcome binding was reduced in post-hypnotic involuntary action compared to voluntary action. It is proposed that intentional binding is driven by a cue combination mechanism and that these differences reflect varying precision of motor intention related information in reported timing judgements. The SWASH was found to be a reliable hypnosis screening instrument.

Declarations

The thesis conforms to an 'article format' in which the middle chapters consist of discrete articles written in a style that is appropriate for publication in peer-reviewed journals in the field. The first and final chapters present overviews and discussions of the field and the research undertaken.

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Chapter 4 is written in the style of an article appropriate for Consciousness & Cognition.

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree. However, the thesis incorporates to the extent indicated below, material already submitted as part of required coursework and/or for the degree of:

1. BSc Neuroscience with Cognitive Science (awarded by Sussex University)

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Chapter I
General Introduction

The sense of agency is the experience we have of being the initiator of our actions and controller of their outcomes (Haggard & Chambon 2012). The experience of agency is central to human experience and, because it supports attributions of responsibility, is foundational to the formal and informal structures upon which societies depend (Haggard, 2017; Moore, 2016). Distortions of sense of agency can occur in a wide range of conditions, but are most widely recognised as a central feature of certain neurological disorders (e.g., corticobasal syndrome) and psychiatric disorders (e.g., schizophrenia; Moore & Fletcher, 2012; Rowe & Wolpe, 2015).

The experience of involuntariness is the central feature in all hypnotic responding (Weitzenhoffer, 1980). Therefore, hypnosis is characterised by changes in the sense of agency (Polito, Barnier & Woody, 2013). Despite this, there has been very little empirical research relating hypnosis directly to contemporary scientific investigations of the sense of agency (Terhune, Cleeremans, Raz & Lynn, 2017). The work in this thesis draws predictions from the cold control theory of hypnosis, which posits that to respond hypnotically is to perform a voluntary action but to (intentionally) experience the action as involuntary (Barnier, Dienes & Mitchell, 2008; Dienes, 2012; Dienes & Perner, 2008). Specifically, cold control theory predicts that the ability to respond to hypnotic suggestion reflects relatively low conscious access to information relating to intentions. Conversely, the practice of mindfulness meditation centrally involves awareness of intentions (Grossenbacher & Quaglia, 2017) and so experienced mindfulness meditators might be expected to develop improved conscious access to intentions (consistent with this suggestion, experienced meditators have been found to be less hypnotisable than non-meditators; Dienes et al, 2015; Semmens-Wheeler & Dienes, 2012a).

The research presented in this thesis applies measures established in psychological research into the sense of agency to hypnosis and meditation to test the theory that hypnosis and meditation are related in opposing ways to awareness of intentions. The results presented here inform theories of hypnosis, of the sense of agency, of the nature and effects of mindfulness meditation, and of theories of the mechanisms that drive the intentional binding effect (an established measure in sense of agency research). Additionally, the development of a hypnosis screening procedure informs theoretical approaches to the induction of hypnosis and provides a more efficient tool for identifying hypnotisability.

The sense of agency and the experience of volition

The sense of agency presents an elusive target for empirical research as it is complex, consisting of various elements (e.g., an experience of intention over causes, a sense of initiation and a sense of control; Pacherie, 2007) and has an ambiguous phenomenology (Gallagher, 2012). The experience of agency has been described as phenomenologically “thin” (i.e., not as “crisp and vivid” as other experiences; Metzinger, 2006, p.20), as it is generally pre-reflective, forming a background to experience rather than being the focus of attention (Gallagher, 2012; Haggard & Eitam, 2015). However, some intentional actions produce relatively “thick” phenomenology (Bayne & Pacherie, 2007) and if expectations are violated and the sense of agency over an outcome is lost (as when a routine action fails to produce the anticipated outcome), the experience can be striking (Haggard, 2007).

Theorists have proposed a division of sense of agency into two components, distinguishing between a background, implicit or pre-reflective sense of agency and explicit, reflective judgements of agency, e.g., whether or not one was the agent in a particular case (Bayne & Pacherie, 2007; David, Newen & Vogeley, 2008; Gallagher, 2012; Synofzik, Vosgerau & Newen, 2008). However, opinions differ as to whether a pre-reflective sense of agency supports reflective judgements of agency (e.g., Bayne & Pacherie, 2007; Gallagher, 2012; Synofzik, Vosgerau & Voss, 2013) or if the two components are fully independent (e.g., Chambon, Filevich & Haggard, 2014).

The sense of agency has to distinguish between actions and outcomes that are intended and those that are not (even a sneeze might have significant consequences when holding a hot drink on a crowded bus). Distinctions between voluntary and involuntary action can be made on the basis of relative influence of endogenous and exogenous processes. For example, reflex actions driven by neuronal activity in the spinal cord might be considered to lie at the opposite end of a spectrum from actions generated by high level cognitive processes which are relatively distal from external influence (Schuur & Haggard, 2011). An alternative approach (at least for animals capable of the communication of introspection) is to draw a distinction between voluntary and involuntary action based on reported experience (Frith, 2013).

Contemporary research into sense of agency primarily arises from two theoretical approaches, which differ in the emphasis they place on different cues in the generation of sense of agency. The theory of apparent mental causation (Wegner & Wheatley, 1999) proposes the relatively strong influence of external contextual cues. Here, sense of agency depends on three aspects surrounding an action-outcome event: it must be associated with a prior thought, it must be consistent with that thought and there must be minimal causal ambiguity regarding the outcome (for a thorough treatment and criticisms see Wegner, 2004). There is plentiful evidence consistent with this theory (Wegner, 2002). For example, participants report agency over a mouse cursor they do not control if the cursor stops on an image which is consistent with a presented word (Wegner & Wheatley, 1999). A second example comes from a study of "vicarious agency", in which the experimenter's arms were so placed as to give the visual impression that they belonged to the participant (Wegner, Sparrow & Winerman, 2004). Here, participants reported a stronger sense of agency over the experimenter's arm movements when they heard prior instructions about the movements. However, there may be some cases in which a sense of agency can occur without consistent prior thought (e.g., in 'flow states'; see Carruthers, 2010). Furthermore, the theory of apparent mental causation may downplay the role of internal motor system information, which is likely to provide a relatively reliable cue for agency judgements (Synofzik, Vosgerau & Voss, 2013).

By contrast, in motor comparator models of agency efferent predictions of the sensory information arising from action-outcomes are compared to afferent information, with a sense of agency arising if there is a close match between predicted and afferent information (Frith, Blakemore & Wolpert, 2000). The comparator model of sense of agency has, for example, been employed to explain why we are generally unable to tickle ourselves, and there is neurobiological and behavioural evidence consistent with this proposal (Blakemore, Frith, and Wolpert, 1998; 2000). There is also evidence for changes in activity in the parietal cortex and cerebellum accompanying a hypnotically suggested experience of involuntariness consistent with a comparator model of sense of agency (Blakemore, Oakley & Frith, 2003). However, a comparator model is unable to accommodate a wide range of experimental results, and therefore does not sufficiently explain the generation of the sense of agency (see Carruthers, 2012; Frith, 2012). For example, in Wegner et al's (2004) vicarious agency study, participants' judgements of agency were based on observation of the movements of others and, as their own arms were not moving, these judgements could not have been based on efferent motor information.

The failure of existing models to accommodate the full range of experimental results relating to sense of agency has led to the proposal of theoretical models which argue that the sense of agency arises from a combination of internal, external, predictive and retrospective cues (Moore, Wegner & Haggard, 2009; Synofzik, Vosgerau & Lindner, 2009). These approaches draw on models of cross-modal cue combination which have been employed to explain the perception of purely external stimuli. Information from multiple modalities must be combined to disambiguate information streams and create stable perception of the environment (for reviews see Ernst & Bülthoff, 2004; Seilheimer, Rosenberg & Angelaki, 2014). One strategy for cue combination is integration by maximum-likelihood estimation (MLE), in which the reliability of a sensory estimate is increased by combining signals from different modalities based on the relative precision (or inverse variance) of each cue (e.g., Alais & Burr, 2004; Ernst & Banks, 2002). Moore & Fletcher (2012) argue that the integration of cues in the generation of sense of agency is a case of maximum-likelihood estimation and that therefore the relative reliability of a cue determines its weighting in generating the sense of agency (e.g., in situations where motor intention-related information is relatively unreliable, external agency cues should dominate)[1]. For

[1]In cross-modal perception of e.g., spatially or temporally located stimuli, there will always be a time or a place of an external object to be estimated. Applying a similar model to sense of agency requires that it is a constant feature of the environment (like time or space). Synofzik (2015) argues that this arises from the repeated experience of contingencies in relation to a minimal self.

example, in Wegner, Sparrow & Winerman's (2004) vicarious agency experiment, the absence of motor intention related information would result in the relatively high weighting of external visual cues in forming an experience of agency.

Measuring sense of agency

The sense of agency can be investigated by explicit subjective reports; for example, asking participants to respond to questions about whether or not they were responsible for a particular outcome (e.g., Ritterband-Rosenbaum et al, 2011) or rate how much agency they felt over a particular action (e.g., Sato & Yasuda, 2005; Wegner et al, 2004). Explicit reports of judgements of agency may be susceptible to demand characteristics and, given the theoretical distinction between reflective and pre-reflective sense of agency, might influence the target of investigation (Wolpe & Rowe, 2014).

Implicit measures have also been developed to measure sense of agency. Such measures are sensitive to agency, but require no explicit agency-related reflection and are therefore relatively protected against demand characteristics. However, it is unclear as to whether or not implicit measures and explicit measures are measuring the same target. For example, a partial dissociation has been demonstrated between explicit judgements of agency and intentional binding (Ebert & Wegner, 2010; Moore, Middleton, Haggard & Fletcher, 2012) but there is also evidence that implicit measures may be dissociable both from each other and from explicit judgements of agency (Dewey & Knoblich, 2014).While many authors argue that explicit and implicit measures may reflect the theoretical division between explicit judgements of agency and implicit, pre-reflective sense of agency (e.g., Ebert & Wegner, 2010; Moore, Middleton, Haggard & Fletcher, 2012; Obhi & Hall, 2011), addressing this question through empirical research presents a considerable challenge (Moore & Obhi, 2012).

Sensory attenuation is the reduced perceived intensity of a sensory stimulus arising from intentional action outcomes compared to externally triggered events (for a review see Hughes, Desantis & Waszak, 2012). This effect is thought to reflect the successful prediction of afferent information relating to action outcomes as described by a motor comparator model of sense of agency. Experimental evidence for sensory attenuation comes from varied methods including explicit report of self-tickling (Blakemore, Frith & Wolpert, 2000), signal detection theory approaches (Cardoso-Leite, Mamassian, Schütz-Bosbach, & Waszak, 2010), force matching tasks (Shergill et al, 2005) and brain imaging showing a relative reduction in the sensory processing of self-triggered auditory (e.g., Martikainen, Kaneko, & Hari, 2005) or visual (e.g., Hughes & Waszak, 2011) stimuli compared to externally triggered stimuli.

The intentional binding effect is a compressed time interval between intentional action and outcome when an outcome (typically an auditory tone) arises from an intentional action rather than a passive movement (Haggard, Clark & Kalogeras, 2002; for reviews see Hughes, Desantis & Waszak, 2012; Moore & Obhi, 2012; Wolpe & Rowe, 2014). The effect has been investigated using direct estimation of interval between action and outcome (e.g., Engbert, Wohlschläger & Haggard, 2008), by dichotomous judgement of synchrony (e.g., Cravo, Claessens & Baldo, 2011) or by reports of the judged time of action and outcome events (Haggard, Clark & Kalogeras, 2002). In the latter method, participants report judgements of the position of a rapidly moving clock hand at the time of an occurrence of an action or of an outcome event. These timing judgements are taken in two conditions: a contingent condition in which the action causes the outcome, and a baseline condition in which each event occurs in isolation. Measured in this way, intentional binding consists of opposing shifts between the perceived time of events in baseline and in contingent conditions: a shift of the outcome event toward the time of action (outcome binding) and a shift of the action towards the outcome (action binding).

Intentional binding studies have provided evidence consistent with cue integration models of agency. For example, Moore & Haggard (2008) report that action binding can occur in the absence of an action-outcome when it is predictable (suggesting a role for sensorimotor prediction) and in the presence of an outcome when it is not predictable (suggesting a role for external cues). Furthermore, priming of action effects has a greater effect in passive than in voluntary action, an effect which may be attributable to increased weighting of primes in the absence of efferent sensorimotor information (Moore, Wegner & Haggard, 2009).

Awareness of intentions

The experience of volition in intentional action can be studied by the use of explicit report of the perceived time of an intention to move, known as W judgements (by contrast with reports of the perceived time of action, or M judgements; Libet et al, 1983). Pacherie (2007) distinguishes between three forms of intention: future intentions (for which the goal is distal), present intentions (involving specific plans regarding the achievement of a goal in the present circumstances) and motor intentions (sensorimotor representations driving ongoing motor action in the pursuit of a goal). While Pacherie considers W judgements to be a measure of present intentions, the timing of intentions is likely to draw on efferent information relating to motor intentions and therefore might be best considered as corresponding to Pacherie's concepts of both present and motor intentions (Gallagher, 2012). Here, the term motor intention will be used in a broad sense to describe the cognitive processes which may support W judgements. For example, activity in the presupplementary motor areas (preSMA) prior to movement (which when averaged produces the readiness potential (RP); Shibisaki & Hallett, 2006) is considered to at least partly support awareness of motor intentions (e.g., Lau, Rogers, Haggard & Passingham, 2004; Libet, Gleason, Wright & Pearl, 1983).

In a famous series of studies, participants watched an oscilloscope 'clock' and reported the perceived position of the clock 'hand' when they experienced an urge to move (Libet et al, 1983). Because the average time of onset of the readiness potential occurred before the average time of reported W judgement, Libet concluded that therefore, we become aware of our intentions after they have been initiated. Libet's proposal generated considerable controversy, with criticisms aimed at both the empirical and philosophical assumptions supporting his conclusions (Freeman, Libet & Sutherland; see commentaries in Libet, 1987, 1999). Recently it has been argued that rather than a slow buildup of activity toward action, the RP is an artefact arising from the time locking of electroencephalography (EEG) signals to movement onset which reflects a stochastic decision process (Schurger, 2012; Schurger, Mylopoulos & Rosenthal, 2016). Drawing on this account, Schmidt, Jo, Wittmann & Hinterberger (2016) argue, therefore that differences in the Libet task (e.g., such as related to motor impulsivity; Caspar & Cleeremans 2015) might reflect differing propensity to act on information reflected in negative deflections of slow cortical potentials. Libet's method has been employed to investigate hypnotic involuntariness; Haggard, Cartledge, Dafydd & Oakley (2004) tested the effect of a post-hypnotic suggestion of involuntariness on M judgements.

Metacognition and Higher Order Thoughts

Metacognition can be broadly defined as cognition about cognition (Flavel, 1979). Nelson & Narens (1990, 1994) distinguish between an object level of cognitive processing and a meta-level which monitors and controls it. The meta-level is sometimes considered synonymous with conscious awareness (e.g., Koriat, Ma'yan & Nussinson, 2006), while other authors argue that metacognitive processes can be unconscious (e.g., Timmermans, Schilbach, Pasquali & Cleeremans, 2012). According to Rosenthal's higher order thought (HOT) theory of consciousness (Rosenthal, 2005; for a review of HOT theories see Carruthers, 2007), consciousness is a metacognitive process in which an unconscious first order cognitive state become conscious only when one has a HOT representing that one is in that state (Rosenthal, 2005). Such HOTs are not equivalent to introspective-awareness, as a second-order HOT will only become conscious if there is another (third-order) HOT about it. Rosenthal's HOT theory assumes no particular functional role for consciousness as first order states, including intentions, have their causal and functional properties by virtue of which they are the states they are, quite independent of HOTs (Rosenthal, 2008).

Therefore, according to HOT theory, it is possible that intentions can occur in the absence of awareness of intentions and that a tendency to have awareness of intentions can vary both according to context and between individuals. There is some evidence that HOTs are supported by activity in the prefrontal cortex (PFC), and in particular the dlPFC (for reviews see Lau & Rosenthal, 2011; Passingham & Wise, 2012; for a conflicting view see Bor, Schwartzman, Barrett & Seth, 2017; Kozuch, 2013).

Hypnosis

Hypnosis involves compelling changes in subjective experience which arise from the delivery of imaginative suggestions within a hypnotic context (i.e., the person delivering the suggestions is designated as a 'hypnotist'; Kihlstrom, 2008). Hypnotic suggestions can be categorised according to whether they require a motor or a perceptual-cognitive response, and also whether they suggest a particular experience will occur or a challenge that a behaviour or percept will be inhibited (Woody & Barnier, 2008; Woody, Barnier & McConkey, 2005). An example of a direct motor suggestion is that the subject will raise their arm and an example of a motor challenge suggestion is that they would be unable to raise it. Similarly, a successful response to a perceptual cognitive suggestion might require a positive hallucination (e.g., hearing music) or a negative hallucination (e.g., being unable to see a ball which is has been placed on the floor). Hypnotic responding is partly characterised by the verisimilitude of suggested experiences (Kihlstrom, 2008). However, the central feature common to all hypnotic responding is the experience of involuntariness over a mental or physical act (e.g., Lynn, Kirsch, & Hallquist, 2008; Weitzenhoffer, 1980).

In scientific research, the ability to respond to hypnotic suggestion (hypnotisability) is measured by the use of standardised scales, which consist of an induction (delivered from a script) and a set of imaginative suggestions (for reviews see Terhune & Cardeña, 2016; Woody & Barnier, 2008). Hypnotisability scores can be generated by recording dichotomous responses for each suggestion, based on behavioural indicators of a successful response (e.g., Bowers, 1993). While such 'objective' scoring is commonly employed, subjective scales which allow participants to provide a quantitative measure of changes in experience may help distinguish between genuine hypnotic responding and conformity (Bowers, Laurence & Hart, 1988). Hypnotisability can be considered a stable trait (Morgan, Johnson & Hilgard, 1974; Piccione, Hilgard & Zimbardo, 1989) but, when tested out of the hypnotic context, reliable correlates of hypnotisability are few and explain little of the variation in hypnotic responding (Dienes et al, 2009). Response expectancies have been found to correlate with hypnotisability (Braffman & Kirsch 1999), but still leave much of the variability in hypnotic responding unexplained (Benham, Woody, Wilson & Nash, 2006). The strongest predictor of ability to respond to an imaginative suggestion following a hypnotic induction is the ability to respond to an imaginative suggestion without an induction (Braffman and Kirsch, 1999). Individual differences in hypnotisability may therefore at least partly reflect differences in a specific ability to experience involuntariness in response to imaginative suggestions.

Woody and Sadler (2008; see also Kirsch & Lynn, 1998; Lynn & Green, 2011) draw a broad distinction between sociocognitive theories and dissociation theories of hypnotic responding. Sociocognitive theories (e.g., Spanos, 1986; Lynn, Rhue & Weekes, 1990; for a review see Lynn, Kirsch & Hallquist, 2008) argue that hypnotic responding can be explained in the same terms as other social behaviours, while dissociation theories (e.g., Hilgard 1992; Kihlstrom, 1985; for a review see Woody & Sadler, 2008) argue for an innate mechanism which specifically supports hypnotic responding. In sociocognitive theories, hypnotic responding is goal-directed and changes in experience occur as a direct result of contextual expectations about the hypnotic situation (e.g., that it will involve the experience of involuntariness (see Green, Page, Rasekhy, Johnson, & Bernhardt, 2006).

In dissociation theories, hypnotic responding arises from a dissociation between either cognitive control processes and behaviour (dissociated control) or between cognitive control processes and experience (Woody & Sadler, 2008). The important distinction here is that in dissociated control, hypnotic involuntariness reflects a genuine lack of top-down control, while in dissociated experience (as in sociocognitive approaches) hypnosis is goal-directed and driven by top-down processes. Hilgard's neo-dissociation theory (1977, 1992), proposes that the experience of involuntariness in hypnotic responding is due to an 'amnesic barrier' between the monitoring and control processes of an ‘executive ego’; Hilgard, 1986, p.234), and is therefore an example of dissociated experience. Conversely, dissociated control theory (Woody & Bowers, 1994) argues that executive processes supported by the frontal lobes are weakened in hypnotic responding, so that actions are triggered without executive control by a contention scheduling system which (according to Norman and Shallice, 1986) normally drives habitual behaviour. Dissociated control approaches conflict with a large body of evidence supporting the role of top-down cognitive processing in hypnotic responding (for a review see Terhune, Cleeremans, Raz & Lynn, 2017).

While proponents of sociocognitive approaches claim that hypnosis involves no special mechanisms over and above those used to describe other social behaviours, there is consensus that reports of hypnotically-induced phenomena reflect genuine changes in experience (Lynn, Hirst & Hallquist, 2008). Sociocognitive theories (e.g., Spanos, 1986) propose that changes in experience in hypnosis arise directly from, for example, expectation and motivation and appropriate strategies (e.g. directing attention, engaging in goal-directed fantasies). A twist on this idea can be found in response set theory (Kirsch & Lynn, 1997; Lynn, Rhue & Weekes, 1990) which draws on the theory that the experience of agency is a retrospective illusion (Wegner, 2002) to argue that all behaviour is unintentional. On this approach, the lack of awareness of the cognitive strategies employed to fulfil strategic goals in hypnotic responding is therefore no different to a lack of awareness of cognitive strategies in solving a mathematical puzzle (Lynn et al, 1991).

The cold control theory of hypnosis (Dienes & Perner, 2007; Dienes, 2012; see also Barnier, Dienes & Mitchell, 2008) provides a parsimonious unifying path through varied theoretical approaches to hypnosis. This interpretation draws on a central implication of HOT theories; intentions, as first order states, are unconscious (Rosenthal

2008; for a review of empirical evidence for unconscious goal-directed behaviour see Custers & Aarts, 2010). According to cold control theory, hypnotic responding is attributable to alterations in HOTs directed at first order intentions. For example, a successful response to hypnotic suggestion that one's arm will rise involuntarily involves an intact first order motor intention, but an inaccurate HOT directed at it. Therefore, hypnotic responding requires the ability to form and maintain inaccurate HOTs of intending.

Cold control theory is not restricted to explaining response to motor suggestions, as cognitive-perceptual suggestions are also claimed to arise as a result of changes in HOTs of intending. For example, experiencing a hypnotically suggested hallucination requires that the subject intentionally imagines the suggested percept, but generates and maintains an inaccurate HOT of that intending. A central implication of cold control theory, therefore, is that hypnosis should produce no special abilities; any behaviour an individual can perform in a hypnotic context they should also be able to perform out of the hypnotic context and without the experience of involuntariness. Cold control theory is therefore consistent with the proposal that hypnotisability may be composed of a core ability and domain specific abilities (Woody, Barnier & McConkey, 2005). This may partly explain why pass-rates are so much lower for cognitive-perceptual suggestions than for motor suggestions; it is perhaps more common to be able to intentionally raise one's arm than to intentionally imagine a percept which in the absence of an experience of intending could pass as a hallucination (it may also be more difficult to avoid a HOT of intending to hallucinate than to perform a motor action; Dienes & Perner, 2007).

Cold control theory is consistent with dissociation theories in that a particular mechanism is proposed to underlie hypnotic responding (but note that cold control theory is not only applicable to the hypnotic context and the ability to form and maintain inaccurate HOTs of intending may support a wide variety of phenomena in which goal directed behaviour is experienced as unintended, e.g., spirit possession or channeling, automatic writing or glossolalia; Dienes & Perner, 2007). The theory is also in agreement with sociocognitive theories that argue for a central role for expectation and context and that hypnotic responding is goal-directed and intentional (e.g., Kirsch & Lynn, 1997; Spanos 1986) and not with dissociated control theories.

There have been few published studies which directly test the predictions of cold control theory. However, Dienes & Hutton (2013) report increased hypnotisability arising from disruption of dlPFC (a brain area which may support HOTs; Lau & Rosenthal, 2011) by repetitive transcranial magnetic stimulation (rTMS). Additionally, Semmens-Wheeler, Dienes and Duka (2013) report increased hypnotisability following administration of alcohol, which the authors argue reflects a reduction in metacognitive ability arising from alcohol-induced disruption of prefrontal cortex (see also evidence that alcohol reduces metacognitive awareness of mind-wandering; Sayette, Reichle, and Schooler, 2009).

So hypnotic responding involves contextually triggered changes in the sense of agency, which may rely on an ability to form and maintain inaccurate HOTs of intending. This may reflect an ability to rely more on external cues to agency (e.g., suggestions from a hypnotist) than internal cues (e.g., motor intentions) in a hypnotic context.

Mindfulness meditation

Mindfulness (a 19th century translation of the Pali word *sati;* Bodhi, 2011) is an important concept in Buddhist meditation practice which has come to be an influential in the West through its adoption in psychotherapeutic techniques, perhaps most famously in Jon Kabat-Zinn's Mindfulness-Based Stress Reduction (MBSR) program (Kabat-Zinn, 2011). Clinical, psychological and neuroscientific mindfulness research has expanded rapidly since the late 1990s and is now applied to diverse areas including primary, secondary and higher education, business and leadership (Williams & Kabat-Zinn, 2011), and clinical interventions derived from Buddhist meditation practice have been demonstrated to be effective in improving psychological health (Hofmann, Sawyer, Witt & Oh, 2010; Keng, Smoski & Robins, 2011) .

In Buddhist sources, there is no single definition of mindfulness, as the concept has developed through a wide variety of scholastic traditions (Dreyfus, 2011; Gethin, 2011) and the varied definitions within traditions are often obscure (e.g., 'not wobbling' or 'not drifting'; Dreyfus, 2011) or established in metaphor (e.g., as a guard watching the doors of a house, Gethin, 2011). Kabat-Zinn (2003) defines mindfulness as "the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment" (p.145). This emphasis on present moment awareness and a non-judgmental attitude toward thoughts is a common feature of Western definitions of mindfulness (e.g., Bishop et al, 2004; Kristeller, 2007). However, such an approach may mischaracterise the Buddhist concept of mindfulness, which fundamentally involves remembrance, and also making judgements about particular mental states in progressing toward a particular ethical goal (Bodhi, 2011; Dreyfus, 2011; Gethin, 2011; Kuan, 2012). Therefore, an attitude of non-attachment or acceptance in mindfulness is perhaps better communicated by the term equanimity, which Desbordes et al (2015) define (in relation to mindfulness) as "an even-minded mental state or dispositional tendency toward all experiences or objects, regardless of their affective valence (pleasant, unpleasant or neutral) or source” (p.357). This concept should be considered distinct from indifference, which, while apparently similar, can be considered as oppositional to equanimity (Bodhi, 2000); thus an attitude of curiosity is sometimes used to characterize mindfulness (compare the Pali metaphor of mindfulness as a surgeon’s probe to gather information, Analayo, 2003, p. 53). One can feel equanimity towards pleasant or unpleasant mental states, while judging one such mental state (consistent with the task at hand) should be sustained in awareness and another let go.

Mindfulness practice is derived from the central teaching of the Buddha on mindfulness, the *Satipatthana Sutta*. This work consists of a series of discourses (purportedly in the words of the Buddha) which present a number of meditation practices to develop mindfulness within four domains (Analayo, 2003). While the first of these domains relates mindfulness to awareness of the body, the remainder all involve awareness of mental states (Dienes et al, 2015). Therefore, the metacognitive monitoring and control of cognitive processes is centrally involved in mindfulness practice (e.g., in monitoring and redirecting attention; Bishop et al, 2014; Brefczynski-Lewis et al, 2007).

Dahl, Lutz & Davidson (2015; see also Lutz, Slagter, Dunne & Davidson, 2008) identify two styles of meditation within an attentional family of mindfulness meditation practices common to multiple Buddhist traditions including Zen, Vipissana and Tibetan Buddhism. Examples of focused attention practices include *samatha* meditation within the Theravadan tradition, which has the aim of developing concentration (*samadhi*; Kuan, 2012**).** Focused attention meditation involves maintaining attentional focus on a single object, for example, one’s own breath. Such focused attention is distinct from that common every day (for example when absorbed in an activity) as it requires the metacognitive monitoring of mental states (or “meta-awareness’” Dahl, Lutz &

Davidson, 2015, p.516), to prevent attention drifting from the object. Note that, contrary to secular definitions of mindfulness as non-judgmental, this process requires assessing whether a particular mental state is consistent with intentions (Dreyfus, 2011; Gethin, 2011).

By contrast, in open-monitoring meditation there is no pre-selected object of attention. Rather, the "attentional scope is expanded to incorporate the flow of perceptions, thoughts, emotional content and/or subjective awareness" (Dahl, Lutz & Davidson, 2015, p.516). Open monitoring practices are therefore metacognitive. Open monitoring techniques are, for example, related to the Theravadan tradition of insight or vipissana meditation, with the aim of developing a direct understanding of the nature of things (Kuan, 2012). When meditation includes insight, attention is not held on one mental content but expands to consider properties of mental states, such as their transience or felt ownership, relevant to the Buddhist analysis of flourishing. Novice meditators are often introduced to focused attention techniques before open monitoring, as metacognitive skills developed by focused attention meditation may aid open monitoring (Lutz, Slagter, Dunne & Davidson, 2008).

Theoretical approaches that propose a key role for metacognition in mindfulness meditation may also be supported by the Buddhist literature. For example, a contemporary Buddhist scholar, Kuan (2012) finds support for interpretations of *samatha* and *vipissana* meditation as processes of metacognitive monitoring and control in the Theravadan Pali canon:

> "Some psychologists suggest that mindfulness corresponds to metacognition. My study shows that this correspondence can be corroborated by Buddhist literature since *sati* 'mindfulness' consists in steering *saññā* 'cognition' in such a way that one's cognition is rendered wholesome in a Buddhist sense. While mindfulness and concentration both involve attention (*manasikāra*), mindfulness in particular plays a pivotal role in

> regulating attention. In the case of *vipassanā* (insight) meditation, attention is regulated by mindfulness in such a way that it is not focused on a single object, but is directed to monitor the ever-changing experiences from moment to moment in a way conformable to Buddhist doctrine, so that the practitioner attains ‘metacognitive insight’ whereby he recognizes the nature of all things as impermanent, unsatisfactory and not-Self. In the case of *samatha* (serenity) meditation, in order to attain the state of ‘concentration’, one has to concentrate one's attention on a single object. Mindfulness picks an object as the focus of ‘selective attention’, that is *ekagga* ‘one-pointedness’ in Buddhist terminology, and monitors whether attention is focused on the chosen object to ensure that the state of concentration is maintained.” (p.55)

So, there is agreement between secular and Buddhist theorists that mindfulness is a form of metacognition. While metacognition of intentions is part of the fourth application of mindfulness described in the *Satipathana Sutta* (Analayo, 2003), it is not generally presented of being of particular significance to mindfulness meditation. However, arguably metacognition of intentions is central to both focused attention and open monitoring practice. In focused attention meditation, one must sustain an intention to maintain concentration on a particular object, during which other intentions may arise, and these must be monitored and controlled in order to sustain attention. Repetti (2010) argues, therefore, that metacognition of intentions is at the core of mindfulness meditation practice, and that it develops awareness of intentions:

> “Meditation cultivates an increasing awareness of pre-conscious, impersonal cognitive/volitional forces that fuel distractions, engage and direct attention, and trigger actions, and it simultaneously cultivates volitional detachment and liberation-oriented volitions and metavolitions. As the practitioner becomes more aware of behavioral triggers, she becomes more able to refrain from acting on them. Thus, Meditation is a form of metamental training that increases volitional self-regulation (autonomy).” (p.177)

Grossenbacher & Quaglia (2017) present a parsimonious model of mindfulness meditation which places a central emphasis on metacognition of intentions. The Contemplative Cognition Framework identifies three constructs as being central to mindfulness and meditation: intended attention, attention to intention and awareness of transient information (or present moment awareness). Here, attention is defined as a process that modulates the efficiency of other ongoing processes and intention is defined as a process of motivation that specifies a goal and makes further processing to achieve that goal more likely. Awareness entails conscious experience and makes cognitive representations available to other processes (e.g., Baars, 1997; Cleeremans & Jiménez; 2002). These three distinct attention related processes together constitute the cognitive processes that characterise mindfulness meditation. Grossenbacher & Quaglia distinguish between intentions to attend and attention to intentions, and argue that it is the interplay of these in relation to attention to transient information (in the present moment) which constitutes mindfulness meditation. Mindfulness meditation therefore involves intentions to attend in the present moment; focused attention involves an intention to pay present moment attention to a particular object (and the intention to notice when attention drifts from this object; Latham, 2016), while in open monitoring the intention is to pay attention to any mental states which happen to arise. Successfully maintaining an intention to attend in the present moment requires the metacognitive monitoring and modulation of intentions, of both the intention to attend and of any conflicting intentions that may arise.

Latham (2016) relates OM and FA meditation to higher order thought theories, drawing on a simple distinction between 1st order states (which are not about other mental states) and higher order states (which are about other mental states). On this interpretation, the intention to pay focused attention to an object (as in FA practices) is an intention to maintain a 1st order metal state, which is likely to also involve an intention to notice whenever attention shifts from the object. Fulfilling such an intention requires a HOT about the contents of the 1st order state. Open monitoring practices, on the other hand can involve the monitoring of both 1st and 2nd order mental states by higher order states (depending on which mental states arise). However, OM may still involve HOTs of 1st order intentions, as such mental states may be amongst those arising during monitoring. Long-term meditation practice may develop enhanced phenomenology of HOTs (just as experienced artists or musicians are capable of more detailed perceptions relating to their area of expertise), which in turn may improve metacognitive monitoring (Latham, 2016).

So, Buddhist meditation fundamentally involves practicing metacognition of 1st order intentions, and therefore may develop finer-grained HOTs of intending. The centrality of awareness of intentions to Buddhist practice has been related to the experimental tradition pertaining to awareness of intentions in psychological science. For example, Dreyfus (2011) argues that mindfulness practitioners “should be able to distinguish more carefully their own intentions and the degree to which those precede their actions or fail to do so” (p. 53) and Repetti (2010, p.207) that “meditators scores on the temporal disparity between neural volitions and mental volitions will be significantly less than those of non-meditators”. Consistent with these suggestions, there is evidence that Buddhist meditators may have improved access to negative deflections of slow cortical potentials which, when averaged, produces the readiness potential (Jo, Wittmann, Hinterberger & Schmidt, 2014; see also Jo, Wittmann, Borghardt, Hinterberger & Schmidt, 2014). Furthermore, there is evidence that meditators are less hypnotisable than non-meditators, perhaps because they have finer-grained concepts of 1st order intentions (Semmens-Wheeler, 2013; Dienes et al 2015).

While there is evidence that meditation may improve a range of cognitive functions, e.g., attention and memory (for reviews see Chiesa, Calati & Seretti, 2013; Tang, Hölzel & Posner, 2015), there is little empirical research relating to the proposal that experienced meditators may have improved metacognition in other domains.

However, there is some consistent evidence from longitudinal studies of mindfulness training; metacognitive judgements of accuracy in a memory task are improved following a 2-week mindfulness meditation intervention (Baird, Mrazek, Phillips & Schooler, 2014), and the frequency of self-caught mind wandering is increased following mindfulness meditation training (Mrazak et al, 2012; Levinson et al, 2014; Zanesco et al 2016).

Aims of the thesis

The main aim of this thesis was to explore predictions arising from the cold control theory of hypnosis – that different levels of trait hypnotisability and experience of mindfulness meditation would be reflected in cognitive measures which may be sensitive to metacognitive access to first order intentions. A secondary aim was to investigate whether or not explicit reports of the experience of involuntariness in hypnotic responding are reflected in an implicit measure of sense of agency. Finally, in order to increase the viability of hypnosis research to the wider research community, we aimed to produce a more efficient instrument for identifying individual differences in trait hypnotisability.

Chapter II employed an established paradigm to explore temporal judgements relating to the experience of volition. Across three studies, Libet clocks were used to compare the time of participants' intentional motor actions to the time at which they experienced an intention to move. In the first study, data was collected from participants pre-screened for trait hypnotisability and experienced Buddhist mindfulness meditators. It was predicted that if hypnotisability is related to higher order access to first-order intentions, high hypnotisables would report later W judgements than low hypnotisables and meditators earlier W judgements than non-meditators. In the second and third studies, hypnosis and meditation-naive participants completed a Libet clock task, were screened for hypnotisability and completed a mindfulness questionnaire to investigate relationships between these measures and trait mindfulness. It was predicted that there would be an inverse relationship between hypnotisability and both W judgement time and self-reported mindfulness.

Chapter III investigated predicted differences in experienced Buddhist meditators and age-matched controls in an established implicit measure of sense of agency - intentional binding. Intentional binding may be driven by a cue combination mechanism in which the judged time of action or outcome events is an average of the temporal sensory information arising from each cue, weighted by precision of information. It was hypothesised that greater metacognitive access to motor intention-related information in meditators would be reflected in opposing patterns in the two components of binding: the shift of reported outcome time toward the action (outcome binding) and the shift of the reported time of action toward the outcome (action binding). Specifically, greater access to motor-intentions in meditators was predicted to increase precision of information relating to action-timing, increasing the weighting of the action cue over both action and outcome time judgements and resulting in decreased action binding and increased outcome binding. Greater precision of action judgements was also predicted to be reflected in the variance of reported action time judgements.

Chapter IV employed an intentional binding task in voluntary action, passive action and post-hypnotic involuntariness to investigate reports of involuntariness in hypnotic responding. In passive action, no motor intention information is available. It was hypothesised that the reported experience of involuntariness in hypnotic responding arises from the avoidance of motor intention-related information in the generation of higher order thoughts of intending. Compared to intentional action, there should be less motor intention information available to support conscious timing judgements in both passive action and post-hypnotic involuntariness, and therefore less precision of action timing judgements. Thus, in the voluntary action condition there should be less variable action timing judgements, less action binding and more outcome binding than in the passive action and post-hypnotic involuntariness conditions.

In Chapter V, an intentional binding task was performed by high and low hypnotisable participants. The aim of the study was to investigate predictions relating to the cold control theory of hypnosis and theoretical models of cue combination as a mechanism driving intentional binding. Greater metacognitive access to first order motor intention-related information was predicted to support relatively high precision of action timing judgements in low hypnotisables. In comparison to high hypnotisables, low hypnotisables were thus predicted to show less action binding, greater outcome binding and less variable timing of action judgements.

Chapter VI presents normative data for a new hypnosis screening procedure (the Sussex-Waterloo Scale of Hypnotisability (SWASH) based on the Waterloo-Stanford Group C (WSGC) Scale of hypnotic susceptibility (Bowers, 1993). The primary aim was to produce an effective and time-efficient hypnotisability assessment tool which could increase the accessibility of hypnosis research to scientists interested in employing hypnosis instrumentally to reliably induce changes in conscious experience, e.g., changes in the experience of agency. A second aim was to reflect contemporary theoretical understanding in the induction script. Practical aims were addressed by including a subjective scale in addition to the dichotomous behavioural scoring of the WSCG to better capture changes in experience (and not merely behavioural response), making adaptations to increase the number of participants who could be screened in single session and decreasing the length of the induction script to reduce the time required for a screening session.

Chapter II

Metacognition of intentions in mindfulness and hypnosis

Abstract

In a famous series of experiments, Libet investigated the subjective timing of awareness of an intention to move, a task that can be considered a metacognitive judgement. The ability to strategically produce inaccurate metacognitions about intentions has been postulated to be central to the changes in judgements of agency common to all hypnotic responding. Therefore, differences in hypnotisability may be reflected in Libet's measure. Specifically, the ability to sustain inaccurate judgements of agency displayed by highly hypnotisable people may result from their having coarser higher order representations of intentions. They therefore should report a delayed time of intention relative to less hypnotisable individuals. Conversely, mindfulness practice aims at accurate metacognition, including of intentions, and may lead to the development of finer grained higher order representations of intending. Thus, the long-term practice of mindfulness may produce an earlier judgement of the time of an intention. We tested these groups using Libet's task, and found that, consistent with predictions, highly hypnotisable people reported a later time of intention than less hypnotisable people and meditators an earlier time than non-meditators. In a further two studies we replicated the finding that hypnotisable people report later awareness of a motor intention and additionally found a negative relationship between trait mindfulness and this measure. Based on these findings, we argue that hypnotic response and meditation involve opposite processes.

General introduction

Voluntary actions can be distinguished from involuntary or reflex actions in that they can, on reflection, be accompanied by awareness of intending to act, as investigated in the famous experiments of Libet and colleagues (Libet, Gleason, Wright & Pearl, 1983). In these studies, participants reported the time at which they experienced an 'urge' to move (W) whilst watching an oscilloscope ‘clock’. As such, Libet's W timing can be interpreted as a measure of temporal metacognition and as a chronometric measure of the sense of agency (Wolpe and Rowe, 2014). We use it to investigate the nature of both hypnotic responding and mindfulness, which both have, we argue, essential metacognitive components. We will argue for the relationship between W and both hypnotic responding and mindfulness via higher order thought theory.

Higher order theories of consciousness relate metacognition to conscious experience by arguing that a mental state becomes conscious by virtue of a second order process that is about it (Lau and Rosenthal, 2011). For example, a visual percept (e.g., “a red ball”, the first order state because it is about the world) becomes conscious by one becoming aware of it with a higher order state (e.g. one with the content, “I see a red ball”, higher order because it is about a mental state). Therefore, Libet’s W judgements can be interpreted as depending on higher order states targeting first order intentions. Changes in higher order processing (i.e. involving states about mental states) may be expected to result in changes to the content of consciousness. Conversely, if normal events elicit unusual experiences, it may be hypothesised that higher order states are being employed in unusual ways.

Differences in the ability to experience hypnotic effects are considerable, and they can be measured using standardised scales based on the number of hypnotic suggestions to which an individual responds (Laurence, Beaulieu-Prevost, du Chene, 2008; Woody & Barnier, 2008). As will be explained, it is possible to describe the unusual experiences of hypnosis as resulting from changes in higher order states. The classical hypnotic suggestion effect is characterised by the experience of involuntariness, with control instead attributed to the hypnotist or to some feature of the hypnotic suggestion (Weitzenhoffer, 1980). Alterations of the sense of agency are therefore central to hypnotic responding (Polito, Woody & Barnier, 2013), and this may provide a clue as to where to look to find reliable predictors of hypnotisability.

A broad distinction can be made between theories of hypnosis that propose that hypnotic responding is intentional and those that do not. For example, according to dissociated control theory (Woody & Bowers, 1994), hypnosis causes a dissociation between action generation and executive control systems. In this case metacognitive judgements of agency during hypnotic responding are accurate, as subjects genuinely have no executive control over the action, and judge that they do not. A second theoretical approach argues that hypnotic responding is intentional (or under executive control), and is due to changes in self-monitoring (e.g, Kihlstrom, 1992; Spanos, 1986). The common denominator of the latter group of theories has been dubbed “cold control” (Dienes, 2012). The word “cold” is used, because the theory supposes that intentional actions are carried out in the absence of an appropriate higher order thought (HOT).

Cold control theory draws on Rosenthals’s HOT theory (Rosenthal, 2005) and proposes that the changes in the conscious experience of intending that define a hypnotic experience are the result of inaccurate HOTs about not having a first order intention. Therefore, hypnotic responding is made possible by an ability to relinquish metacognition related to voluntary behaviour in response to a hypnotic situation (Dienes, 2012). So, by this account, an ideomotor suggestion to raise an arm results in a normal first order intention to raise the arm (cf. Schlegel, Alexander, Sinnott-Armstrong, Roskies, Tse, & Wheatley, 2015). However, the intention fails to become conscious because there is no accurate HOT that might ordinarily be directed at the first order intention if a voluntary movement were being attended to ("I am intending to move my arm"). There is in fact a directly contrary HOT, appropriate to the hypnotic situation, but inappropriate to the facts ("I am not intending to move my arm", which constitutes a HOT broadly construed as a state about the nature, including non-existence, of first order states; contrast Rosenthal, 2005). So, hypnotic responding requires an inaccurate HOT related to an intention, not merely the absence of an accurate HOT. If highly hypnotisable people are better able to form inaccurate HOTs of intending, this ability may be supported by their having a generally weaker coupling of HOTs to first order intentions (Semmens-Wheeler & Dienes, 2012). Such a weaker coupling may be reflected by later awareness of an intention to move.

Mindfulness can be defined as the cultivation of equanimous awareness of present experience as present experience, while sustaining that experience or letting it go according to task purposes (e.g. Williams & Kabat-Zinn, 2013). For example, if the aim is to attend to the breath, when experiences unrelated to the breath arise they are judged as task unrelated, and allowed to pass; but experiences of the sensation of the breath on the lip are judged as appropriate and sustained. These judgments are made without feelings of disappointment or triumph. Mindfulness meditation is thus intrinsically an exercise in the (metacognitive) control and monitoring of mental processes (Bishop, Lau, Shapiro, Carlson, et al., 2004; Gethin, 2015; Jankowski & Holas, 2014; Teasdale, 1999). But apart from a recent report that mindfulness meditation enhances metacognitive abilities (Baird, Mrazek, Phillips & Schooler, 2014), and evidence that mindfulness is associated with a more fine-grained awareness of emotions (e.g. Hill & Updegraff, 2010), there has been surprisingly little work relating meditation practice to metacognitive measures. Awareness of intentions constitutes part of the four foundations of mindfulness (Analayo, 2003). The four foundations are: First, awareness of the body in terms of its parts, postures and movements; second, awareness of feelings, specifically as pleasant, unpleasant or indifferent; third, awareness of mental states broadly in terms of whether they are conducive to flourishing or not ('deluded', 'concentrated', etc); and, fourth, awareness of mental states classified in a number of detailed ways to bring out their nature and relation to flourishing (Analayo, 2003). The final category includes intentions. (The progression is from the more concrete given content of a mental state to more abstract mental state properties claimed as relevant to flourishing by Buddhist theory.) Buddhist scholars have also argued that the practice of mindfulness should lead to an enhanced awareness of action intentions (Dreyfus, 2013). Therefore, mindfulness meditators might be expected to have an earlier awareness of an intention to move (cf Jo, Hinterberger, Wittmann & Schmidt, 2015, who report that meditators have greater access to the negative deflections of the slow cortical potentials averaged to produce the early readiness potential which is associated with conscious intentions to act).

In summary, we have argued that highly hypnotisable people on the one hand, and meditators on the other, lie at two ends of a spectrum of metacognition or accurate HOTs related to intention (see Lifshitz, Cusumano & Raz, 2014, and Raz & Lifshitz, 2016, for a discussion of different theoretical perspectives on the relation between meditation and hypnosis). In support of this assertion, it has been found that meditators score lower on hypnotisability scales than non-meditators and that highly hypnotisable people score lower on trait mindfulness scales than low hypnotisables (Semmens-Wheeler & Dienes, 2012).

We used a variation of Libet's experimental method to time the conscious awareness of an intentional action in high, medium and low hypnotisable subjects, and in mindfulness meditators. Since cold control theory proposes that hypnotic responding relies on an ability to generate inaccurate HOTs of intending, it was predicted that the highly hypnotisable group would report an awareness of their intention as occurring later than other groups. On the basis that mindfulness meditation may lead to a tighter metacognitive coupling between first order intentions and their related HOTs, we predicted that mindfulness meditators would report an earlier W time than non-meditators.

Study 1

Study 1 method

Participants

Twelve long-term meditators with at least three years of meditation practice were recruited from Buddhist organisations in Brighton. One meditator was excluded as they reported an inability to read clocks. So, data from eleven meditators were analysed (5 males, 6 females; mean age = 37.8, *SD* = 16.4) with a mean of 12.7 years of meditation experience (*SD*=10.6) and a mean of 14.7 hours per month meditation (*SD*=11.3). Meditators were asked to provide details of their practice in simple terms and all reported using a form of mindfulness meditation.

Fifty-four undergraduate participants of varying hypnotisability were recruited from the University of Sussex hypnosis screening database. Eight reported prior experience of meditation and were excluded, so data from seven highly hypnotisable (1 male, 6 females; mean age =19.6, *SD* =2.1), nineteen low hypnotisable (19 females; mean age = 20.3, *SD* =6.9) and twenty medium hypnotisable subjects (3 males, 17 females; mean age = 23.0, *SD* =6.0) are reported. Using a standard test of hypnotisability (Waterloo-Stanford Group Scale of Hypnotic Suggestibility, Form C (WSGC; Bowers, 1993) participants categorised as highly hypnotisable scored nine or above from a possible twelve (*M* = 9.29, *SD* = 0.50). Medium hypnotisable participants scored between four and eight (*M* = 6.00, *SD* =1.41) and low hypnotisable subjects scored three or below (*M* = 1.95, *SD* = 1.22).

Participants were recruited for the duration of one term, until there were no more responses. Bayesian analyses were used to assess sensitivity. As stopping was not conditional on a function of the p-value, orthodox statistics assuming fixed N could be used (Cox & Mayo, 2010, section 10.1). Crucially, we used Bayesian analyses to indicate the strength of evidence for H1 versus H0; the measure of evidence is valid no matter what the stopping rule.

Ethical approval was received from the University of Sussex ethics committee and informed consent was obtained from each participant before commencing with the study. Participants received cash payment of £5 or course credits.

Apparatus and materials

The apparatus, controlled by a PIC microcontroller, comprised two connected units: a clock (figure 1) and a switch assembly. The clock had a conventional face, but the hour labels (1, 2, 3 … 12) were replaced with minute labels (5, 10, 15 … 60). The clock's single hand was driven by a stepper motor, requiring 2,400 steps to complete one revolution. The motor was pulsed every millisecond, thus one revolution took 2.40 s and the "minute" marks on the face represented increments of 40 ms. When participants reported values on the clock face, these were converted to the equivalent number of milliseconds from the twelve o'clock (60) mark. The clock was connected to a switch, the contacts being closed by a light metal sleeve, worn on the participant's finger. The sleeve was lined with soft foam, the arrangement being designed so that no tactile information was available to indicate whether the switch was closed or not; this could be deduced only via proprioceptive feedback. In the rest position the finger, with its conducting sleeve, rested across the two contacts of the switch, completing the circuit. Raising the finger broke the circuit, and the time registered by the clock at that moment was recorded by the microcontroller with 1 ms resolution. The result was shown on a seven-segment display, oriented out of sight of the participant. The finger could be lifted voluntarily, but there was also a mechanism by which the experimenter could cause the finger to rise. This facility was not used in the experiments reported here.

All participants were asked to complete the dissociative experiences scale II (DES-II, Carlson & Putnam, 1993) One meditator did not complete the DES-II.

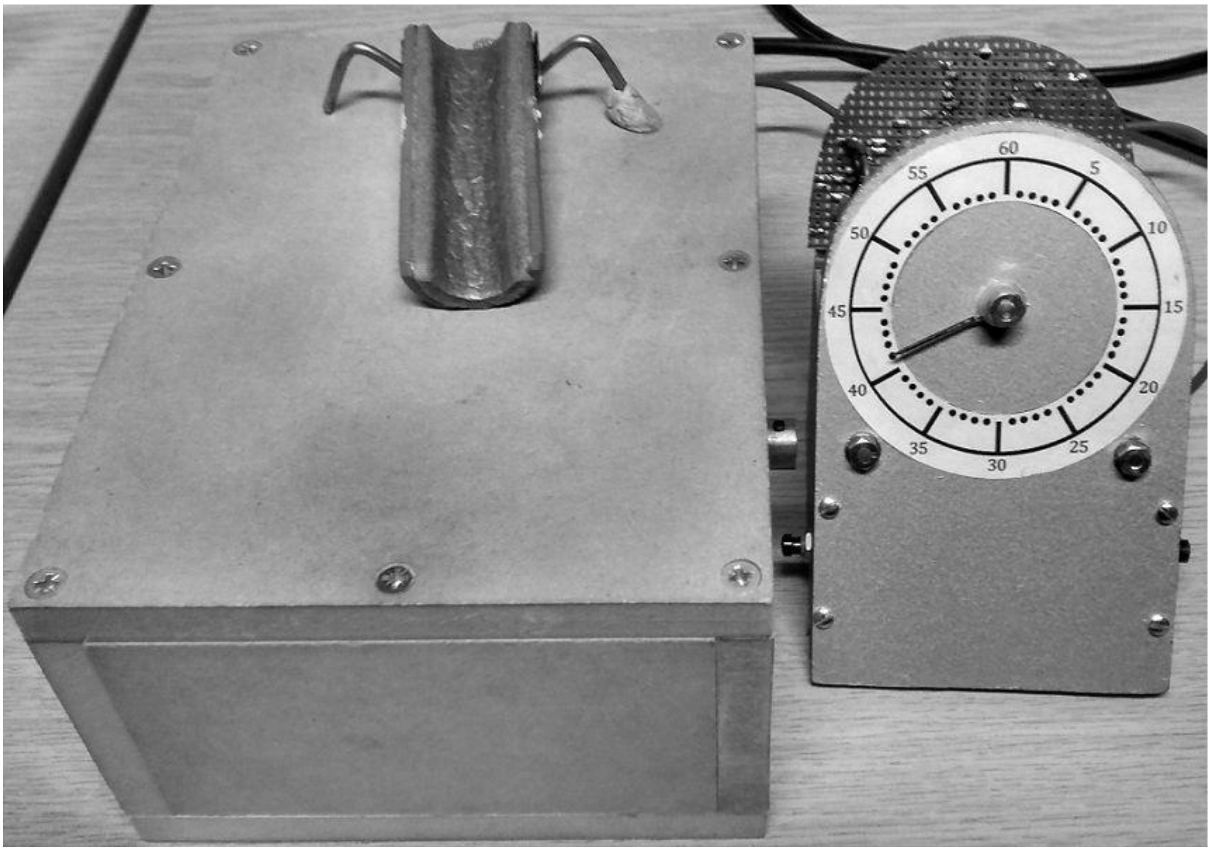

Figure 1: The clock apparatus.

Procedure

The experiment was adapted from Libet et al (1983). Subjects carried out five practice trials and forty test trials (two blocks of twenty trials with a five-minute rest period). Participants were asked to rest their finger upon the switch assembly to complete the circuit, then to wait for one full revolution of the clock hand before lifting their finger at a time of their choosing. They were asked not to plan ahead or to aim for a particular time. After raising their finger, they were asked to replace their finger and then to report the time indicated by the clock at which they had first experienced their immediate intention to move (a W judgement). They were instructed to make full use of the clock face in reporting (rather than rounding the time on the clock to the nearest five-unit marker). The time at which the circuit was broken was recorded, together with the stated clock time.

Analysis

Finger-lift times (in milliseconds) were subtracted from the subjective report of the timing of immediate intention (converted to milliseconds) to give a numerical value for the difference between the timing of the reported intention and the moment at which the circuit was broken (W). Time differences on individual trials with values greater than 3 *SD* from the mean were excluded for each participant (21 trials in total, 0.9% of all trials). Mean scores for time difference were taken for each group and, following convention, a negative number was used to denote that the awareness of intention occurred before the circuit was broken and a positive number that it occurred afterwards.

The interquartile range of judgement errors was compared between groups to assess whether there were differences in attention to the task. Mean DES-II scores were calculated for group comparison and correlation analysis.

Bayes factors (*B*) were used to assess strength of evidence (cf Wagenmakers, Verhagen, Ly, Matzke, Steingroever, Rouder, & Morey, in press). A *B* of above 3 indicates substantial evidence for the alternative hypothesis and below 1/3 substantial evidence for the null. *B*s between 3 and 1/3 indicate data insensitivity (see Jeffreys, 1939; Dienes, 2014). In order to indicate how strongly evidence supports a hypothesis, one has to specify what the hypothesis predicts; i.e., for H1, one needs to specify roughly the sort of effect predicted, as for example based on a relevant past study. Williams et al (2011) found a difference of 230 ms in W timing between functional motor disorder patients and a control group. It has been proposed that such functional disorders rely on the same mechanisms as hypnotic response (Bell, Oakley, Halligan, & Deeley, 2011), so the effect is relevant. Assuming 230 ms is a rough maximum effect we could expect given it was found comparing a clinical population to controls, Bayes factors for W timing group differences were calculated using a half-normal distribution with *SD* = 115ms. Although here we interpret the results with respect to Bayes Factors, p values are also provided for each analysis.

Bayes factors for correlations of hypnotisability with other measures were calculated using a half-normal distribution with *SD* = .30 based on the moderate correlations reported between hypnotisability scores and other cognitive or questionnaire-based measures (e.g., Laurence et al, 2008). As directional predictions were not made for correlations between hypnotisability and gender or age the Bayes factors for these correlations were calculated using a full-normal. Here, $B_{H(0, x)}$ refers to a Bayes factor where H1 is specified as a half-normal distribution with a mean of 0 and SD of *x* (for directional predictions), and $B_{N(0, x)}$ indicates H1 was specified as a normal distribution with mean 0 and SD *x* (for non-directional predictions). Bayes factors and t-tests were corrected for unequal variance by the procedure of Box and Tiao (1972, p 107) for adjusting standard errors and degrees of freedom.

The 3-df effect of group was decomposed into three contrasts. Specifically, the effect of hypnotisability was evaluated in terms of a linear trend (highs versus lows) and a quadratic trend (mediums versus the average of highs and lows). Finally, meditators were contrasted with mediums because the relative numbers of participants in each hypnotisable group do not reflect their proportions in the population (approximately 10% of the population are high and 10% low hypnotisable by conventional thresholds). The B's for these three contrasts were multiplied together to obtain an "omnibus B" evaluating the predictions of cold control versus H0. Support for cold control was taken as being shown by evidence: for a linear trend of hypnotisability versus H0; for H0 versus a quadratic trend; and for a difference between meditators and mediums versus H0. The resulting omnibus B assumes that the B for each contrast tests predictions independently of the other contrasts in the precise sense that the effect size tested in each contrast would not be relevant to updating the predicted effect size for the other contrasts (Jeffreys, 1939, pp 269-270). We include omnibus B only for completeness so that wherever we give a p-value we also give a B, but in fact no conclusions will depend on omnibus B's in any case.

Bayes factors for DES-II analysis were calculated with a full normal based on half the difference between highs and lows (24 points) reported in Terhune, Cardeña & Lindgren, (2011).

H1 for interquartile range analysis was specified using a uniform from 0 to the medium hypnotisable groups' inter-quartile range, specified as $B_{U[0,m]}$ where *m* is the maximum of the uniform distribution. The interquartile range can be normalized with a log transform, which also provides a "data translated" likelihood especially suitable for Bayesian analyses when a uniform is used to specify predictions (Box & Tiao, 1972).

A Bayes factor for age difference between meditators and mediums was calculated using a half normal with SD based on the minimum number of years of meditation experience (3) used as a criterion for selection.

Study 1 results

We will first consider the key predictions regarding the timing of awareness of intentions. Then we consider two more secondary issues: Any role of dissociative experiences as measured by DES-II; and finally any differences in sustaining attention on the task, as measured by the consistency of the W response.

Figure 2 shows mean time differences and confidence intervals for the four groups. A Welch one-way ANOVA on the time differences (W timings) between the four groups indicated that the groups differed, $F(3, 24.63)= 16.54$, $p < .\ 0.001$, omnibus $B_{H(0,\ 115)}= 2570.41$. There was a linear trend of hypnotisability on W judgements, $t(22.76)= 3.84$, $p = .003$, $d = 1.22$, $B_{N(0,\ 115)}= 92.01$. There was no quadratic trend, $t(44)= .042$, $p = .966$, $d = 0.013$, $B_{N(0,\ 115)} = .23$. Finally meditators reported earlier W judgements than mediums, $t(28.78)= 3.04$, $p = .007$, $d = 0.95$, $B_{N(0,\ 115\ )} = 22.27$. Pearson's coefficient was used to test for correlations. A correlation between WSGC (hypnotisability) score and W was found, $r(47)= .30$, $p = .043$, $B_{H(0,\ .30)}= 5.43$.

There was evidence that the mean age of meditators ($M = 37.8$, $SD = 16.4$) differed from medium hypnotisables ($M = 23.0$, $SD = 6.9$, t(12.0) = 2.87, $p = .014$, $B_{H(0,\ 3)} = 2.98$. The evidence was not sensitive as to whether or not there was a within-group correlation between age and W judgements, (Fisher z-transformed) $r(57) = -.069$ (SE = .13) $B_{N(0,\ .30)} = .45$. But crucially, a one-way ANCOVA showed that, after accounting for age, mean W differed between meditators ($M = -149.1$ ms, $SE = 29.3$) and medium hypnotisable non-meditators ($M = -68.5$, $SE = 20.6$), F(1,28)= 4.36, $p = .046$, $B_{H(0,\ 115)} = 4.40$.

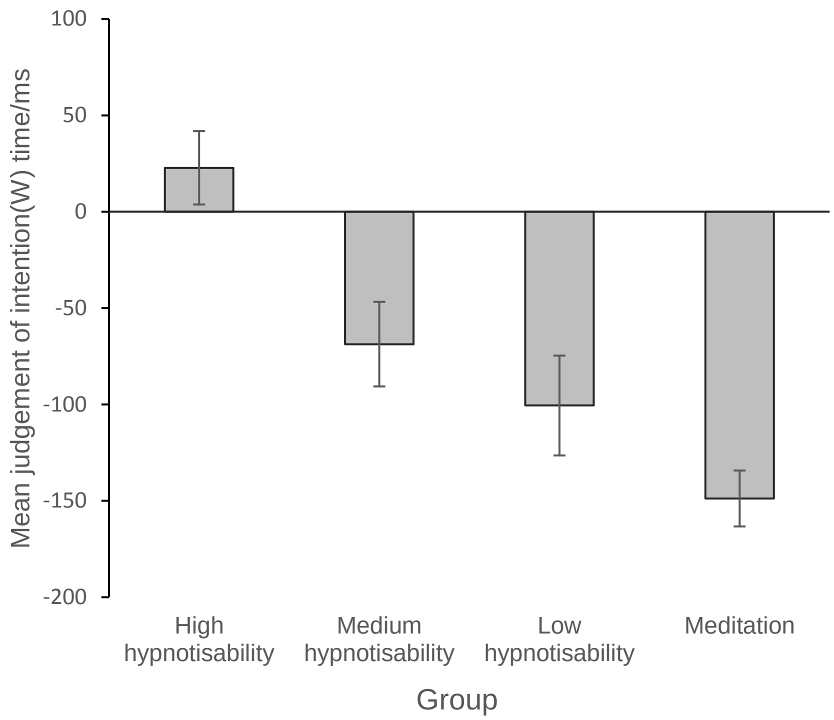

Figure 2: Mean time differences between the retrospectively self-reported time at which a volitional immediate intention to perform a motor action was experienced and the moment at which the movement occurred. Error bars show 95% CIs (the CIs can be treated as credibility intervals with uniform priors).

Turning now to dissociative experiences, the evidence was insensitive as to whether or not there was a correlation between W and DES-II score, $r(56) = .015$, $p = .911$, $B_{H(0, .30)} = .44$. DES-II and WSGC scores correlated, $r(49) = .473$, $p = .001$, $B_{H(0, .30)} = 79.45$. A contrast between highs ($M = 31.22$, $SD = 15.59$) and lows ($M = 14.3$, $SD = 7.7$) revealed a linear trend of hypnotisability on DES-II scores, $t(7.09) = 2.75$, $p = .028$, $d = .57$, $B_{H(0, 12)} = 3.95$, and there was no evidence one way or the other for a quadratic trend, $t(44) = .497$, $p = .621$, $B_{N(0, 12)} = .47$. Meditators ($M = 11.5$, $SD = 9.8$) differed from mediums ($M = 20.8$, $SD = 3.1$), $t(23.4) = 2.18$, $p = .040$, $d = 0.88$, $B_{H(0, 12)} = 4.70$.

Finally, we consider group differences in sustaining attention to the task, as measured by consistency of response; specifically, a participant's inter-quartile range in their W responses. There was no linear trend of hypnotisability on inter-quartile range (highs M = 143.2 ms, SD = 52.2; vs lows, M = 131.9 ms, SD = 46.7) revealed by a t-test conducted on log-transformed values, $t(24)$= .627, p = .537, d = 0.29, $B_{U[0, 2.17)}$ = .07. Meditators (M = 123.0 ms, SD = 40.22) and mediums (M = 168.2 ms, SD = 104.6) did not differ in inter-quartile range. $t(29)$= 1.48, p = .149, d = 0.56, $B_{U[0, 2.17)}$ = 0.23.

Study 1 discussion

The key findings of Study 1 are that highs show an especially late awareness of intentions, consistent with cold control theory. Conversely, meditators show an especially early awareness of intentions, consistent with meditation experience inducing metacognitive changes. We found that these differences did not arise from attentional differences between groups, and therefore they may be purely meta-cognitive.

Dissociation has been found to interact with hypnotisability in executive related tasks (e.g., Terhune, Cardeña & Lindgren, 2011). Thus our conclusions about the relation between high hypnotisability and W judgments may apply only to the sub-group of highs identified by Terhune et al as high dissociating highs. While the high DES-II scores of highs in study 1 prevented investigation of this possibility, further research could usefully select low dissociating highs and lows and determine if the pattern still holds. The association we found between DES and hypnotisability contradicts the null finding by Dienes et al (2009); however, the latter study tested hypnotisability and the DES in entirely unrelated contexts, conditions known to reduce correlations of variables with hypnotisability (Kirsch & Council, 1992). When hypnotisability and DES are tested in the same context, people may interpret the questions of the DES as asking about hypnotic experiences. A possible weakness of the study is that we do not know the hypnotisability of participants in the meditation group. Studies 2 and 3 will assess mindfulness in participant groups in which hypnotisability is known.

Study 2 introduction

Study 2 was a conceptual replication of Study 1 measuring mindfulness with a standard questionnaire in undergraduates rather than by contrasting meditators with non-meditators and investigated whether the early W judgements reported by mindfulness meditators also occur in meditation naïve participants high in trait mindfulness. As hypnotisability was measured on all participants, this study examined the relationship between mindfulness and the timing of an intention to move in groups of known hypnotisability. The study also investigated the relationship between hypnotisability and trait mindfulness. Buddhist traditions suggest that long-term meditation leads to the development of mindfulness skills in everyday life, and experienced meditators have been shown to score higher on the FFMQ than non-meditators (Baer et al, 2008). Therefore, we might not expect meditation-naive participants high in trait mindfulness to display mindfulness related metacognitive abilities to quite the same degree as experienced meditators.

Study 2 method

Participants

Thirty-six meditation-naïve undergraduate students were recruited from the University of Sussex. Following initial examination of the data, two participants were excluded from further analysis as their scores for mean W judgement identified them as outliers by SPSS boxplot. Data from 34 participants were therefore analysed.

Ethical approval was received from the University of Sussex ethical committee and informed consent was obtained from each participant before commencing with the study. Participants were compensated with course credits.

Materials and methods

Participants were screened for hypnotisability using an edited version of the WSGC. This involved a shortened induction and the delivery of one of two selections of five suggestions taken from the WSGC scale. Each set of suggestions contained one motor direct suggestion, two perceptual direct suggestions, one motor challenge suggestion and one perceptual-cognitive challenge suggestion. Participants were randomly assigned to either set of suggestions. Unlike in the WSGC:C, in which participants are screened as a group and therefore report their own objective ratings, because the screening sessions were individual, it was possible for objective ratings to be taken by the experimenter. The WSGC:C does not include subjective ratings and here a further subjective rating was recorded from the participant's verbal answers to a set of standard questions (see online Supplemental Material for the hypnosis scripts and scoring procedure). W timing was measured using the same apparatus and procedures as in Study 1.

Participants also completed a short form of the Five Facet Mindfulness Questionnaire, a 24-item questionnaire which measures five different facets of mindfulness; observing, describing, acting with awareness, non-judging and non-reactivity (FFMQ-SF; Bohlmeijer, ten Klooster, Fledderus, Veehof & Baer, 2011).

Participants were recruited for the duration of one term, until there were no more responses. Bayesian analyses were used to assess sensitivity.

Analysis

Mean judgement errors on the Libet clock task were calculated for each participant as in Study 1. Mean ratings of objective and subjective scores for hypnotisability and scores on the FFMQ-SF were calculated. A combined hypnotisability measure was calculated from the objective and subjective hypnotisability ratings. Both the objective and subjective ratings were measured on a scale of 0 to 5; the combined measure was the simple average of the subjective and objective measures. Results for the individual hypnotisability ratings are presented in the online supplementary materials.

Bayes factors were calculated as in Study 1. A *B* was calculated for the correlation between objective and subjective hypnosis scores using a full-normal with *SD* = .82 (converted to Fisher's Z) based on the average correlation between objective and subjective hypnotisability ratings across three screening procedures reported by Barnes, Lynn and Pekala (2009).

Study 2 results

Subjective (*M* = 2.0, *SD* = 0.8) and objective (*M* = 2.0, *SD* = 1.4) hypnosis ratings correlated, $r(34) = .69$, $p < .001$, $B_{H(0, .82)} = 16439.52$, The combined measure of subjective and objective hypnotisability (*M* = 2.1, *SD* = 1.0) correlated with W judgement, (*M* = -75.0 ms, *SD* = 84.5 ms), $r(34) = .321$, $p = .065$, $B_{H(0, .30)} = 3.76$, and negatively correlated with FFMQ-SF score, $r(34) = -.403$, $p = .018$, $B_{H(0, .30)} = 9.39$.

Study 2 discussion

These results support the relationship between hypnotisability and judgement of intention reported in study 1 and are consistent with evidence that hypnotisability is inversely related to trait mindfulness. However, as there was no sensitive evidence for a correlation between trait mindfulness and W judgements (see supplemental material), no conclusion can be drawn as to whether trait mindfulness is related to metacognition of motor intentions.

Study 3 introduction

Study 3 replicated study 2 but differed in two aspects. First, a computer clock was used. Second, unlike in the first two studies, M judgements (the timing of action) were taken alongside W judgements. Libet considered the M judgement an important part of participant training, and found that when M trials were performed before W trials, W times were significantly more negative (Libet, 1983). However, the use of M judgements to influence identification of the moment of intention has been criticised (Gomes, 1998), and Pockett and Miller (2007) argue that subjects in subjective timing experiments should be kept as naive as possible. The -75ms timing of W reported here in the absence of an M judgement is later than the -200 ms mean W time and close to the -85 ms mean M reported by Libet al al (1983). This might be interpreted as evidence that subjects in these studies misunderstood the request for a W judgement and gave M judgements instead. Study 3 investigated whether the relation between hypnotisability and W would hold when M as well as W judgments are taken.

Study 3 method

Participants

Twenty-nine meditation-naïve undergraduate students were recruited from the University of Sussex. One participant was excluded prior to analysis due to equipment malfunction. Ethical approval was received from the University of Sussex ethical committee and informed consent was obtained from each participant before commencing with the study.

Materials and methods

Participants were screened for hypnotisability using the same procedure as in Study 2.

Visual stimuli were displayed at 100 Hz on a 21" CRT monitor. At the beginning of each trial, a clock face was presented. This was marked at thirty degree intervals and subtended a visual angle of five degrees. A static dot, subtending at 0.2 degrees appeared at a pseudo randomized position for each trial and began rotating around the clock face 250 ms after the clock appeared, performing a full rotation every 2560 ms. Participants were seated at a viewing distance of approximately 60 cm. A computer mouse was used to record actions (button presses).

In separate blocks, participants were asked to press the mouse button at a time of their choosing and to report either the time of the action (M) or the time of their immediate intention or urge to move (W). In both trial types, participants were instructed to allow the dot to complete at least one full revolution before pressing the mouse button. If this instruction was not followed, a warning message was displayed and the trial restarted. Similarly, a warning message was displayed and the trial restarted if the button had not been pressed within six full rotations of the clock.

Participants were asked not to pre-plan their actions. After the button had been pressed, the clock continued moving for a pseudo-randomised period of time between 1200 ms and 2370 ms to prevent any influence from the sudden disappearance of the dot. There then followed a pseudorandomised time interval (500 ms to 1280 ms) during which the clock was not visible on the screen. Timing judgements were then recorded by moving a dot around the clock face and pressing the mouse button.

Each block consisted of 40 repetitions of one trial type and blocks were separated by 30 s rest periods. The two blocks were presented in counterbalanced order. All Stimuli were programmed by Jim Parkinson (University of Sussex) and generated with Matlab (MATLAB 2012b, The MathWorks, Inc., Natick, Massachusetts, United States) running Psychtoolbox v3 (Kleiner et al, 2007).

Participants also completed a short form of the five facet mindfulness scale questionnaire (Bohlmeijer, ten Klooster, Fledderus, Veehof & Baer, 2011), as in Study 2. Two participants failed to complete the questionnaire. These participants were included in all analyses except correlations with the FFMQ-SF.

Participants were recruited for the duration of one term, until there were no more responses. Bayesian analyses were used to assess sensitivity.

Analysis

Mean judgement errors on the Libet clock task were calculated for each participant as in Study 1, but for M (timing of movement) as well as W judgements.

Mean ratings of objective and subjective scores for hypnotisability and scores on the FFMQ-SF were also taken. A combined hypnotisability score was calculated as in Study 2. Results for the individual hypnotisability ratings are presented in the online supplementary materials. The distance between M and W was also calculated for each participant (M/W distance).

Study 3 results

M judgements (M = -17.1 ms, SD = 40.1) correlated with W judgements (M = -143.7 ms, SD = 159.0), Spearman's ρ (28) = .526, p = .004, $B_{H(0, .50)}$ = 44.61. Objective (M = 1.6, SD = 1.2) and subjective (M = 1.7, SD = 1.0) hypnosis ratings were correlated, Spearman's ρ (28) = .690, p < .001, $B_{H(0, .30)}$ = 1307.98. The combined hypnotisability rating (M = 1.6, SD = 1.0), and the derived measure of the distance between M and W were correlated, Spearman's ρ (28) = -.376, p = .049, $B_{H(0, .30)}$ = 4.90. The combined hypnotisability measure correlated with W, Spearman's ρ(28) = .350, p = .068, $B_{H(0, .30)}$ = 3.85. There was no evidence as to whether or not M judgements correlated with the combined hypnotisability measure, Spearman's ρ(28) = .161, p = .414, $B_{H(0, .30)}$ = 1.06.

The evidence was not sensitive as to whether or not FFMQ-SF scores correlated with W, Spearman's ρ (26) = -.136, p = .507, $B_{H(0, .50)}$ = .67, or with the combined hypnotisability score, Spearman's ρ (26)= -.147, p = .472, $B_{H(0, 30)}$ = .98.

Table 1 shows the results of a fixed-effects meta-analysis conducted on the results of studies 2 and 3 to test the overall evidence for correlations. This revealed support for correlations between hypnotisability and W judgement and hypnotisability and mindfulness. The Bayes factor on FFMQ-SF score vs W was insensitive, so no conclusion follows.

	Measure			
	Overall hypnotisability	Subjective hypnotisability	Objective hypnotisability	Mindfulness (FFMQ-SF)
W judgement	.347 (.129) p = .009 [.094, .600] $B_{H(0, .30)}$ = 16.63*	.369 (.129) p = .005 [.117, .622] $B_{H(0, .30)}$ = 24.85*	.270 (.129) p = .041 [.018, .523] $B_{H(0, .30)}$ = 4.88*	-.19 (.131) p = .152 [-.067, .447] $B_{H(0, .30)}$ = 1.76
Mindfulness (FFMQ-SF)	-.306 (.131) p = .023 [-.049, -.564] $B_{H(0, .30)}$ = 7.79*	-.373 (.131) p = .006 [-.115, -.630] $B_{H(0, .30)}$ = 23.98*	-.203 (.131) p = .126 [-.055, -.460] $B_{H(0, .30)}$ = 2.03	

Note. * = sensitive *B* (evidence for the hypothesis). Standard deviations appear in parentheses after means. 95% credibility intervals and Bayes factors are reported below means.

Table 1. Meta-analytically combined Fisher z-transformed Pearson and Spearman's correlations between measures of hypnotisability, mindfulness and timing of intention (W) in studies 2 and 3.

Study 3 discussion

Consistent with predictions, there was evidence that the distance between M and W judgements was inversely related to hypnotisability. This counts against the suggestion that highly hypnotisable people may have confused W with M judgements. The evidence for a relationship between trait mindfulness and hypnotisability was inconclusive in this study, but a meta-analysis of studies 2 and 3 provides support for this relationship. Strong support is also provided for a relationship between hypnotisability and judgement of time of intention across the studies. We were unable to provide any evidence one way or the other for the relation between trait mindfulness and W judgments. Thus, the question of whether meditation practice per se as a training in metacognitive awareness of intentions, rather than trait mindfulness, is crucial to early W judgments remains open.

General Discussion

We used the Libet task to investigate group differences in the timing of the conscious awareness of an action intention (W) in hypnotisable groups and mindfulness meditators. A linear effect of hypnotisability was found on W (cf Kirsch 2011), with highly hypnotisable participants reporting a later W time than less hypnotisable participants. Conversely, mindfulness meditators reported an earlier W time than non-meditators. These differences are supported by a positive correlation between hypnotisability and W timing in two further studies and a negative correlation between hypnotisability and trait mindfulness in a meta-analysis of the results of studies 2 and 3. The results are consistent with the prediction from cold control theory that hypnotisability is inversely related to the coupling of higher order thoughts to first order intentions; that is, most generally, with theories of hypnosis that argue that hypnotic responding involves changes in the monitoring of intentions, rather than changes in executive control. Furthermore, the earlier W timing reported by experienced meditators supports predictions from Buddhist scholars (Dreyfus, 2013) that mindfulness meditation enhances metacognition related to action intentions.

Notably, we have recently found that there is no difference in M judgements between hypnotisable groups and no difference in M between meditators and non-meditators. A fixed-effects meta-analysis was conducted on M judgement differences in meditators reported in Lush, Parkinson & Dienes (submitted) and in Semmens-Wheeler (2012). Mean difference = 6.6 ms, p = .806 [-46.4, .59.7], $B_{H(0, .80)}$ = .27. This B supports there being no difference between meditators and non-meditators in M judgements. However, we report here that W judgements do differ between these groups. As we found evidence for no differences in inter-quartile range, these results are unlikely to be attributable to differences in attention to the task. Jo, Hinterberger, Wittmann & Schmidt (2015) reported no significant difference in W judgements between meditators and non-meditators, but with means showing large effects in the same direction as we found here. A fixed-effect meta-analysis of the standard Libet instruction comparison reported in Jo et al and study 1 revealed strong evidence in favour of an earlier W time in meditators rather than non-meditators (*M* = 76 ms, *SD* = 24.2), $B_{H(0,\,115)}$ = 46.25.

Historically, there has been little agreement as to what the Libet task is measuring (e.g., Dennett & Kinsbourne, 1992; Maoz et al, 2014), and these results may inform that debate. One possible interpretation is that the findings may reflect differences in a threshold or criterion level of the brain activity underlying voluntary movement at which people can become conscious of an intention to move (cf Schurger, Sitt, & Deheane, 2012). On this reading, highly hypnotisable people may have a higher threshold (perhaps resulting from coarser grained concepts of first-order intentional states) and thus take longer to become aware of intending. Conversely, mindfulness practice may lower this threshold (perhaps due to the development of finer grained concepts of mental state properties). Alternatively, it has been argued that consciousness is graded and that the timing of awareness of action intentions may instead reflect a threshold of reportability (Miller & Schwarz, 2014; though contrast Dehaene, Charles, & Marti, 2014, for the argument that consciousness is relatively all-or-none). These findings are consistent with either interpretation. From a higher order theory perspective (e.g. Rosenthal, 2005), whatever pressure brings about possession of concepts of mental states, would not need make such higher order states more fine grained in content than the gradations of first order states themselves. Thus, higher order states will likely make discrete distinctions between first order states (for evidence concerning the extent to which confidence ratings, i.e. higher order thoughts, reflect discrete states see Swagman, Province, & Rouder, 2015). Thus, awareness of first order states (specifically intentions) may be discrete to a degree that varies across individuals (e.g. between high and low hypnotisable individuals) and that can be made more fine grained by practice (e.g. mindfulness meditation). Notably, Schlegel et al (2015) report motor cortex activity associated with intentional action for highs performing actions experienced as involuntary following a post-hypnotic suggestion, consistent with there being no change in first order processes in hypnotic responding.

The related question of how one becomes aware of an intention has been the focus of a large body of research in recent years (e.g., Haggard & Eitam, 2015), with competing accounts proposing retrospective (e.g., Wegner, 2002) or predictive (e.g., Blakemore, Wolpert & Frith, 2002) cues. Current theoretical models propose that the sense of agency is supported by both predictive and retrospective mechanisms (Synofzik, Vosgerau, and Newen 2008), with the relative weighting of each depending on their reliability (so that signals of low noise have a greater influence) (Moore and Fletcher, 2012; Synofzik, Vosgerau, and Voss, 2013). However, this question is largely orthogonal to the hypotheses addressed here.

Recent findings suggest a second possible mechanism underlying the earlier W judgement timing reported by mindfulness meditators. Mindfulness involves not taking the content of mental states at face value, and thus potentially not being drawn to attractive or salient stimuli (e.g. Papies, Pronk, Keesman, & Barsalou, 2015). Possibly meditators in estimating the time of an intention are thus not unduly drawn to the time of the action, allowing an earlier estimate of the time of the intention. However, contradicting this explanation, we have found that meditators compared to non-meditators show more intentional binding, i.e. a process by which the estimated time of one event is drawn towards that of another in an illusory way (Lush, Parkinson & Dienes, submitted).

Group differences in the timing of conscious awareness of intending a voluntary action may provide a route toward exploring related cognitive and neuronal processes. For example, Moore & Bravin (2015) report that increased variability of W judgement predicts high schizotypy scores (although there is evidence for a relationship between schizotypy and hypnotisability (e.g., Connors et al, 2014), we found no difference in W variability between hypnotisable groups). Delays in the timing of W have also been reported in groups with parietal lobe damage (Sirigu et al, 2003), and exploration of the neural processes and architecture supporting the differences reported here may provide further insight into disorders related to the awareness of intention, such as schizophrenia (for a review of disorders of volition, see Kranick & Hallett, 2013). Intriguingly, later W timing has also been found in conversion disorder patients (Edwards et al 2012), suggesting the possibility that cold control theory may provide a way of investigating the often hypothesised link between functional or psychogenic disorders and hypnosis (see Vuilleumier, 2014).

It has been argued that in order to become tractable to empirical investigation, consciousness may need to be theoretically divided into constituent structural properties (Seth, 2009). Phenomena that involve changes in subjective visual perception such as binocular rivalry have been employed to study neural correlates of visual consciousness (e.g., see Maier, Panagiotaropoulos, Tsuchiya & Keliris, 2012). Similarly, the identification of hypnotic responding as changes in the subjective experience of intending may provide a fruitful avenue to investigate the biological substrates of conscious experiences of volition. More generally, the sense of agency is a rapidly growing field of study within psychology (see Moore & Obhi, 2012; Chambon, Sidarus

& Haggard, 2014; David, Obhi & Moore, 2015; Haggard & Eitam, 2015), and the investigation of changes in the sense of agency resulting from hypnosis has the potential to illuminate and inform findings in this area.

In summary, this study reveals individual differences in the timing of a metacognition of action initiation related to mindfulness meditation and hypnotisability. These findings are consistent with the cold control theory of hypnosis and with the proposal that hypnotisability and mindfulness meditation lie at opposite ends of a scale of metacognition related to the conscious awareness of intention (Semmens-Wheeler & Dienes, 2012).

Chapter III

Illusory temporal binding in meditators

Abstract

We investigate conditions in which more accurate metacognition may lead to greater susceptibility to illusion; and thus conditions under which mindfulness meditation may lead to less accurate perceptions. Specifically, greater awareness of intentions may lead to an illusory compression of time between a voluntary action and its outcome ("intentional binding"). Here we report that experienced Buddhist mindfulness meditators rather than non-meditators display a greater illusory shift of the timing of an outcome towards an intentional action. Mindfulness meditation involves awareness of causal connections between different mental states, including intentions. We argue that this supports improvements in metacognition targeted at motor intentions. Changes in metacognitive ability may result in an earlier and less veridical experience of the timing of action outcomes either through increased access to sensorimotor pre-representations of an action outcome or by affording greater precision to action timing judgements. Furthermore, as intentional binding is an implicit measure of the sense of agency, these results also provide evidence that mindfulness meditators experience a stronger sense of agency.

Introduction

Mindfulness is a concept central to Buddhist traditions and can be defined as the cultivation of a calm (hence “non-judgemental”) awareness of present states, especially mental states, and specifically including an awareness of the temporal properties of the ongoing states, such as their transience (Williams & Kabat-Zinn, 2011). While mindfulness practice often starts with awareness of the experiences of breathing, the central mindfulness practice of the Pali canon, Satipatthana, includes cultivating awareness of all mental states, including intentions and their consequences (Analayo, 2004; Gunaratana, 2012). Thus, Dreyfus (2011) argued that mindfulness meditation should lead to cognitive differences in the awareness of intentions, and urges psychologists to explore this possibility. Consistently, mindfulness meditators have been found to report earlier judgements of the timing of an intention to move than non-meditators, suggesting they have more accurate metacognition related to intention (Dienes et al, 2016; Lush, Naish & Dienes, 2016).

The sense of agency can be defined as the sense of being in control of one’s goal directed actions and their outcomes in the world (Gallagher and Zahavi, 2008; Haggard and Chambon, 2012). The modern study of agency can be traced back to the work of Libet, Gleason, Wright and Pearl (1983), in which the timing of a conscious intention to move (W) was related to the ‘readiness potential’ in the motor cortex which precedes voluntary motor actions. Libet et al measured timing judgements by asking participants to watch a rotating ‘clock’ and to retrospectively report the position of the clock ‘hand’ had occupied when they experienced the urge to move. Intentional binding refers to the subjectively reported time compression that occurs between an intentional action and its outcome when compared to the timing of an action alone and of an event that does not depend upon an action (Haggard, Clark and Kalogeras, 2002). It can be measured using

Libet et al's rotating clock method to record the judged time of an action or an auditory tone in two conditions: a contingent condition in which the action causes the tone; and a baseline condition in which the action does not result in a tone or the tone occurs without an action. The effect emerges from the perceived shift of the action toward the tone (action binding) and of the tone towards the action that caused it (outcome binding) in the contingent condition compared to the baseline condition (Moore and Obhi, 2012).

Intentional binding has been employed to investigate disorders that involve changes in the sense of agency, e.g., in schizophrenia (Haggard, Martin, Taylor-Clarke, Jeannerod and Franck, 2003; Voss et al, 2010), alien limb syndrome (Wolpe et al 2013) and functional motor disorder (Kranick et al, 2013) and in pharmacologically induced changes in sense of agency, e.g., ketamine (Moore et al, 2011). There is, however, some evidence that weaker action-effect interval binding can occur in the absence of intention (Buehner, 2012; Wohlschlager, Haggard, Gesierich and Prinz, 2003). Therefore, intentional binding may be a special case of a more general causal binding of actions to their outcomes, with information specific to intentions supporting stronger binding.

There is not yet consensus on the mechanism of intentional binding. The important point is that the proposed mechanisms can agree on intentional binding arising from meta-cognitive processes. Greater awareness of intentions should increase the binding effect. According to one theory, outcome binding arises from accurate prediction of action outcomes (Waszak, Cardoso-Leite and Hughes, 2012). That is, the better one can predict the outcome from the intention, the sooner in time the outcome is perceived as happening. On other theories, the assessed time of each component is affected by a type of anchoring produced by the other event happening. In this case, the greater precision with which an intention and hence an intentional action is timed, the more it will affect the perceived time of the outcome (Kawabe, Roseboom & Nishida, 2013; Moore & Fletcher, 2012). With regard to intentional binding being a measure of sense of agency, the more precisely one represents the outcomes of an intention as intentional outcomes, the more sense one has of acting on an intention; or the more precision with which one represents the intention, the more sense one has as acting on an intention. Thus, on each of these theories, greater awareness of intentions should lead to greater outcome binding, associated with a greater sense of agency.

Because Buddhist mindfulness involves awareness of "dependent origination" i.e. the causal connections between different mental states, including intentions and their outcomes (for example in mindfulness of movements, Gunaratama, 2012), meditators should have greater metacognitive access to their intentions. Meditation is an exercise in metacognitive processes, both in monitoring and control (Jankowski & Holas, 2014) and sustained meditation practice seems likely to lead to changes in metacognition (Dienes et al, 2016). Consistently, meditators have been found to show more accurate metacognition related to the timing of an intention than non-meditators, (Lush, Naish & Dienes, 2016) and experienced meditators have been shown to have greater metacognitive access to negative deflections of slow cortical potentials (which, when averaged, produce the early readiness potential) (Jo, Hinterberger, Wittmann & Schmidt, 2015).

Greater metacognitive accuracy of higher order mental states targeted at motor intentions should influence timing judgements that are dependent on prediction, such as outcome binding. These considerations can be used to make different predictions. On the one hand, meditators may be more accurate in their timing estimates due to improvements in metacognition, and attention resulting from mindfulness practice (Jo et al, 2014). On the other hand, the ability to develop accurate prior expectations concerning the outcome of intentions, and to consistently and reliably use those expectations, could lead to perception of the tone as occurring early. In terms of this mechanism, this could result either from more reliable sensorimotor pre-representations of the outcome tone (Waszak et al, 2012) or through greater precision (and therefore greater weight) being afforded to intentional action in an outcome timing judgement (Wolpe et al, 2013). As there is some agreement that action binding is a result of cue integration, action binding would be smaller in meditators if there is a relative increase in precision of action judgements, reducing the relative contribution of the tone to action timing judgements (Wolpe and Rowe, 2014).

Jo et al. (2014), the one previous study that has addressed the question of intentional binding in meditators, found no significant difference between meditators and non-meditators in intentional binding. However, a non-significant result does not in itself mean there is no effect. To assess the sensitivity of the study to pick up an effect, an estimate is needed of the sort of difference in intentional binding that could be found between different groups. Kranick et al (2013) provided such an estimate using functional motor disorder patients; the difference between groups was on the order of magnitude of about half the effect found in control participants. Based on this estimate, Jo et al's data do not provide evidence for there being no difference in intentional binding between meditators and non-meditators (see online supplemental materials).

We tested mindfulness meditators and age-matched controls on an intentional binding task. If mindfulness increases the relative precision afforded to action timing judgements, then the meditation group should show decreased action binding and increased outcome binding due to improved metacognitive access to motor intentions resulting from a history of sustained attention to intentions and actions. Alternatively, if meditators are more accurate in their timing estimates as a result of improved attentional abilities generally, their reported judgements should be more veridical and they should show less binding of any sort (Jo, Hinterberger and Schmidt, 2014).

Method

Participants

Eight meditators were recruited from Brighton-based Buddhist organisations. Eight age and gender matched controls were recruited by advertisement (3 males and 5 females, mean age = 49.3 years, *SD* = 10.5). The Buddhist meditators (3 males and 5 females, mean age = 49.1 years, *SD* = 9.8) reported a mean of 14.6 years of continuous meditation experience (*SD* = 11.6) and a mean of 23.3 (*SD* = 12.0) hours per month meditation. Meditators were asked to provide details of their practice in simple terms and all reported using a form of mindfulness meditation. All members of the control group reported that they had no experience of mindfulness meditation.

Ethical approval was received from the University of Sussex ethical committee. Informed consent was obtained from each participant before commencing with the study. Participants received cash payment of £5, and were additionally paid £5 in travel expenses.

Participants were recruited for the duration of one term, until there were no more responses. Bayesian analyses were used to assess sensitivity. As stopping was not conditional on the p-value, orthodox statistics assuming fixed N could be used (Cox & Mayo, 2010, section 10.1). Crucially, we used Bayesian analyses to indicate the strength of evidence for H1 versus H0; the measure of evidence is valid no matter what the stopping rule.

Procedure

Visual stimuli were displayed at 100 Hz on a 21" CRT monitor and auditory stimuli were presented via Sennheiser headphones. For each trial, a clock face was presented, marked at thirty degree intervals and subtended a visual angle of five degrees. A static dot, subtending at 0.2 degrees, appeared at a pseudo-randomized position and began rotating around the clock 250 ms later (at 2560 ms per revolution). Participants were seated at a viewing distance of approximately 60 cm. A computer keyboard was used to record actions (button presses).

There were four trial types, presented in separate blocks. In contingent trials, pressing a key triggered a 1000 Hz, 100 ms duration tone after a 250 ms delay. Participants were asked to look at a fixation cross in the centre of the clock and to wait for at least one revolution before pressing the button at a time of their choosing. The trial was restarted if the action occurred before one full revolution or after six revolutions. Participants were asked not to plan ahead or to aim for a particular point on the clock and to report either the action or the tone (to give contingent action or contingent tone judgements). Baseline action trials were the same as contingent action trials except the button did not trigger a tone. In baseline tone trials, the tone was triggered pseudo-randomly between 2.5 s and 7 s following one revolution of the clock.

Following the tone (or action on baseline action trials), the dot continued moving for a pseudo-randomised period of time between 1200 ms and 2370 ms. The clock was then removed from the screen for a pseudorandomised time interval (500 ms to 1280 ms). When the clock reappeared, participants were able to control the position of the dot with a mouse. Moving the mouse forward (toward the screen) caused the dot to move in a clockwise direction around the clock face and the reverse mouse movement (away from the screen) caused the dot to move counter-clockwise around the clock face. Participants were asked to move the dot to the position it had occupied at the time of the judged event (action or tone) and to press the mouse button to record their judgement.

Each block consisted of 40 repetitions of one trial type and blocks were separated by 30 s rest periods. The four blocks were presented in counterbalanced order. Before the session began, all participants were trained with four practice trials in the baseline tone condition and four in the baseline action condition so that they could become familiarised with the reporting procedure. All Stimuli were generated with Matlab (MATLAB 2012b, The MathWorks, Inc., Natick, Massachusetts, United States) running Psychtoolbox v3 (Kleiner et al, 2007).

Measures

Mean judgement errors were calculated for each group on each trial type. Individual judgements more than 3.5 SD from the mean for each participant on each judgement type were excluded before mean judgement errors were calculated for each participant. Nine judgements were filtered by this method ((1.4% of all trials). The adjusted mean errors for action and tone conditions were then subtracted from their respective contingent conditions to calculate action and outcome binding. Finally, outcome binding was subtracted from action binding to produce a total binding measure. We ran independent t-tests to compare the two groups on these measures.

Within-participant SD of timing judgements provides a measure of precision in estimating the time of an event. If binding reflects the combination of cues according to the precision afforded to actions or their outcomes, any differences in intentional binding should be accompanied by differences in this measure. In terms of cue integration theory, it is the interaction between meditators vs controls by tone vs action timing precision that determines changes in intentional binding between groups. If meditators relative to controls have greater precision for actions rather than outcomes, then outcome binding should be greater and action binding less for meditators relative to controls.

Data Analyses

Bayes factors (*B*) were used to assess strength of evidence (Wagenmakers, Verhagen, Ly, Matzke, Steingroever, Rouder, & Morey, in press). Unlike null-hypothesis significance testing, Bayes factors have the advantage of distinguishing sensitive evidence for H0 from not much evidence at all. A *B* of above 3 indicates substantial evidence for the alternative hypothesis and below 1/3 substantial evidence for the null hypothesis. *B*s between 3 and 1/3 indicate data insensitivity in distinguishing null and alternative hypotheses (Dienes, 2014; Jeffreys, 1939). Here, $B_{H(0,\, x)}$ refers to a Bayes factor in which the predictions of H1 were modeled as half-normal distribution with an SD of *x* (Dienes, 2014); the half-normal can be used when a theory makes a directional prediction where *x* scales the size of effect that could be expected (so x can be chosen from e.g., relevant past studies). Kranick et al (2013) provide an estimate of the sort of difference in intentional binding that could be found between different groups using conversion disorder patients; the difference between groups in tone binding was on the order of magnitude of about half the effect found in control participants. Bayes factors for group differences in each measure were therefore calculated using a half-normal distribution with SD based on half the total shift in the control group. The direction we used is that predicted by cue combination and sensorimotor pre-representation theories of intentional binding, given the assumptions discussed in the introduction (Wolpe & Rowe, 2014). That is, the prediction was a greater outcome binding for meditators rather than controls, but a reduced action binding.

Bayes factors for solo action judgement group contrasts were calculated using a full-normal with SD = 80 ms based on the difference between meditators and non-meditators in the timing of an intention to move (Lush, Naish & Dienes, 2016). H1 for analysing differences between meditators and controls in standard deviations (SD) was specified using a uniform from 0 to the control groups' SD, specified as $B_{U[0,m]}$ where *m* is the maximum of the uniform distribution. A Bayes factor for the interaction of group and within participant SD in baseline action and outcome trials was calculated using a uniform from 0 to the largest simple effect difference between groups (Dienes, 2014).

Results

Figure 1 shows the overall intentional binding measures for each group. Meditators' total binding (M = 168.8, SD = 98.9) was greater than that of age-matched non meditators (M = 71.7 ms, SD = 62.6), $t(14) = 2.34$, $p = .034$, $d = 1.17$, $B_{H(0, 40)=}$ 3.95.

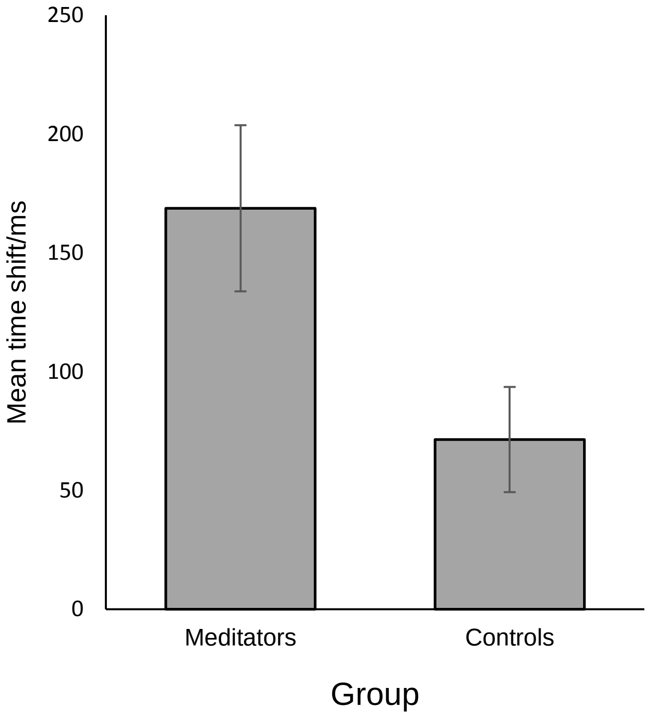

Figure 1. Total binding for meditators and age-matched controls. Error bars show standard errors

Figure 2 shows the action and outcome binding measures for each group. Meditators' outcome binding (M = -138.02 ms, SD = 64.8) was greater than that of non-meditators (M = -60.5 ms, SD = 50.0), $t(14) = 2.68$, $p = .018$, $d = 1.34$**,** $B_{H(0, 32)=}$ 6.57. There was no sensitive evidence for whether or not meditators' action binding (M = 30.7 ms, SD = 45.9) was less than that of non-meditators (M = 13.9 ms, SD = 31.0), $t(13) = .857$, $p = .406$, $d = 0.43$, $B_{H(0, 9)=}$ 0.80. For the prediction of action binding being greater for meditators rather than non-meditators, $B_{H(0, 9)}$= 1.20.

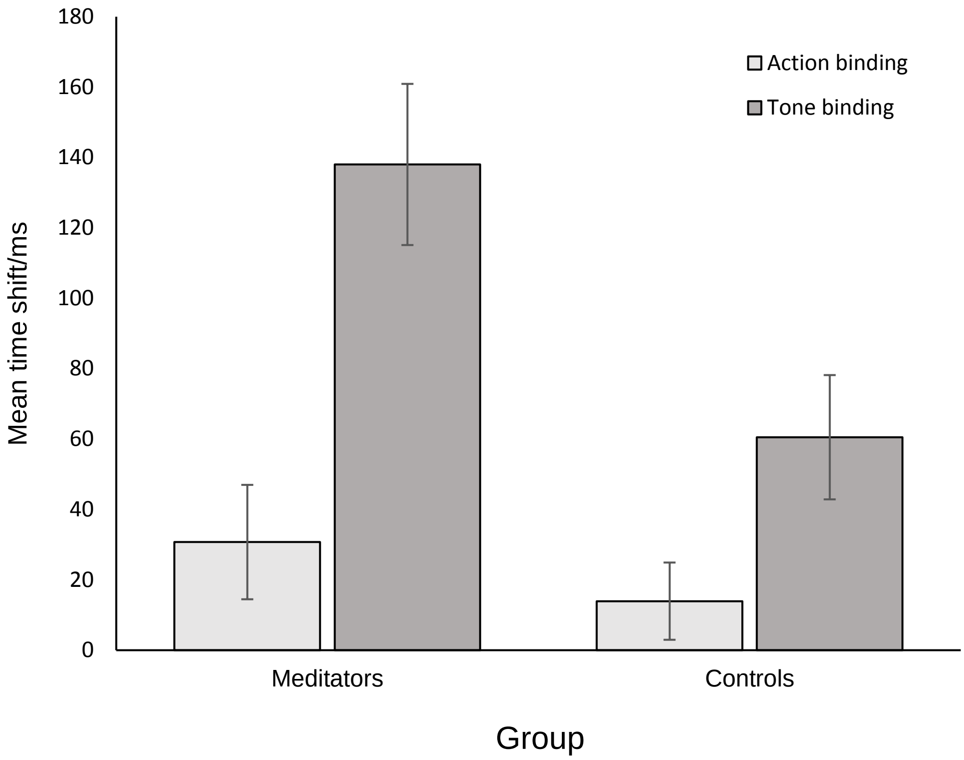

Figure 2. Action and outcome binding for meditators and age-matched controls. Error bars show standard errors

The raw simple effect of meditators' within-participant SDs for baseline action judgements (*M* = 67.6 ms, *SD* = 33.9) was 30.3 ms lower than that of controls (*M* = 98.0 ms, *SD* = 95.5). The raw simple effect of meditators' within-participant SDs for baseline tone judgements (*M* = 79.0 ms, *SD* = 42.9) was 11.2 ms lower than that of controls (*M* = 90.2, *SD* = 47.6), so the raw interaction effect for within participant SD on each measure between groups was 19.1 ms. There was no evidence one way or the other for whether or not there was an interaction, $F(1, 14) = .427$, $p = .524$, $B_{U[0, 30]} = .68$.

Discussion

We found that meditators showed greater subjective compression of the interval between an intentional action and its outcome than non-meditators (intentional binding). Specifically, meditators showed a greater shift in the perceived timing of an event toward the action that caused it; there was no sensitive evidence for a difference between meditators and non-meditators in the shift of action judgements towards its tone (Bayesian analysis showed these data to be insensitive in discriminating H1 from H0, so no firm conclusions can be drawn with regard to accepting the null hypothesis for action binding difference and this non-significant result will not discussed further). Meditators therefore reported a less veridical experience of timing of action outcomes than non-meditators. Furthermore, as intentional binding is considered an implicit measure of sense of agency, this result can be taken to show that meditators have a stronger sense of agency than non-meditators.

There may be different mechanisms underlying the two binding components, action binding and outcome binding (Wolpe, Haggard, Siebner and Rowe, 2013). According to a predictive, sensorimotor model of outcome binding, the effect is due to a decreased latency in the perception of an outcome that results from the pre-representation of the predicted outcome of an action (Waszak et al, 2012). Therefore, an increase in outcome binding may be driven by stronger or more reliable predictive sensorimotor representations of the tone (Synofzik, Vosgerau & Voss, 2013). Alternatively, when an outcome event is contingent upon an action event, the judgement of the time at which a particular event occurs may be a weighted average of each cue (Kawabe et al, 2013; Moore & Fletcher, 2012). In this case, group differences in the timing shift of an outcome toward an action or of an action toward an outcome would reflect group differences in the relative weighting of each cue (on cue integration theory, we should expect lower variance of within participant SD of action judgements than tone judgements; however, the evidence here was insensitive, so we can draw no conclusion as to how our results relate to this theory).

The increased outcome binding in meditators we report here could be attributable to differences in metacognition of motor intentions under both these accounts. Meditators may have more reliable or well specified sensorimotor representations of the predicted outcomes of an action, consistent with the claim that mindfulness involves close attention to concrete experience (Watkins, 2015). Alternatively, on a cue combination approach, meditators would show stronger outcome binding if improved metacognitive access to motor intentions or actions relative to external stimuli (like tones) affords higher precision of action timing relative to outcome timing. In this case, an increase in the weighting of the action cue in outcome judgements would lead to the timing judgement being drawn closer to the time of the action and therefore more outcome binding. In either case, greater accuracy of higher order mental states directed at intentions and their associated actions would, somewhat paradoxically, lead to a less veridical subjective experience of the timing of an intentional action’s outcome. The direct test of differences in precisions between groups for actions relative tones was insensitive, so this explanation is neither directly supported nor ruled out by the data.

Consistent with the suggestion that outcome binding is increased by improved metacognition of motor intentions, there is growing evidence that outcome binding is reduced when the contribution of intentions is reduced. A reduction in outcome binding has been shown to occur when participants incorrectly believed their action did not cause an outcome, a finding which may be attributable to the discounting motor intention related cues in judging the time of an outcome (Desantis, Roussel & Waszak, 2011). A post-hypnotically suggested experience of involuntariness has also been shown to reduce outcome binding (Lush et al, submitted). This finding may also be a result of the reduced contribution of motor intentions to the outcome judgement, as hypnotically induced experiences of involuntariness may be supported by the avoidance of motor intentions in forming metacognitive judgements of agency (Dienes, 2012). Finally, activity in the pre-supplementary motor area (preSMA) reflects motor intentions (Lau, Rogers, Haggard & Passingham, 2004). The disruption of activity in the preSMA by repetitive trans-cranial magnetic stimulation (rTMS) has been found to lead to a reduction in outcome binding (Moore et al, 2010) and the amplitude of the early readiness potential in the preSMA (associated with motor preparation) has been found to positively correlate with outcome binding (Jo et al, 2014).

Jo et al (2014) reported a non-significant difference in intentional binding between mindfulness meditators and age-matched controls. However, Bayes factors can be employed to test evidence for the null hypothesis (Dienes, 2014, Wagenmakers et al, in press, Dienes, 2016), and in fact a meta-analysis of the results of the two studies provides sensitive evidence for an increase in overall binding and outcome binding (see online supplementary materials).

Mindfulness meditators report a slower subjective passing of time and are thought to experience an “extended now” (Wittmann and Schmidt, 2014). However, here we report a shorter estimate of the time interval between an action and its outcome in meditators. These results can be taken to suggest that meditators have a stronger implicit, experiential sense of agency than non-meditators (Ryan & Rigby, 2015). The study of group differences in action-outcome binding may therefore inform our understanding of the sense of agency and consequently disorders which involve distortions in the sense of agency, (e.g., functional motor disorders or schizophrenia).

To this end, mindfulness meditators offer clear advantages over the use of the pharmacological interventions or clinical populations in which previous group differences in action-outcome binding have been observed. For example, the role of predictive cues in intentional binding has previously been studied by varying the probability of an outcome tone occurring (Moore & Haggard, 2008). This method has been used to investigate intentional binding in schizophrenia and could be straightforwardly applied to investigate predictive contributions to outcome binding in meditators (Voss et al, 2010).

We report increased intentional binding, an objective measure of the sense of agency, in meditators over age-matched controls. Specifically, meditators showed a larger shift in the timing of an outcome toward the intentional action that caused it. While meditators here reported a less veridical experience of the timing of an event, we argue that this reflects that compared to non-meditators, mindfulness meditators have improved metacognition of motor intentions.

Chapter IV

Post-hypnotically induced changes in the temporal binding of intentional action outcomes

Abstract

The sense of agency is the experience of initiating and controlling one's voluntary actions and their outcomes. Intentional binding (the compressed time interval between voluntary actions and their outcomes) is increased in intentional action but requires no explicit reflection on agency. The reported experience of involuntariness is central to hypnotic responding, where strategic action is experienced as involuntary. We report reduced intentional binding in a hypnotically induced experience of involuntariness, providing an objective correlate of reports of involuntariness. We argue that reduced binding results from the diminished influence of motor intentions in the generation of the sense of agency when beliefs about whether an action is intended are altered. Thus, intentional binding depends upon awareness of intentions, showing that changes in metacognition of intentions affect perception.

Introduction

The sense of agency is the experience we have of initiating and controlling our voluntary actions and their outcomes (see Haggard & Eitam, 2015). Intentional binding refers to the subjective compression of the time between an intentional action and its outcome, consisting of a forward shift of the judged time of an action toward its outcome (action binding) and the backward shift of an outcome toward the action that caused it (outcome binding). (Haggard, Clark & Kalogeras, 2002). The effect is sensitive to intentional action but requires no explicit reflection upon agency and may reflect the additional contribution of intentions to causal binding (Buehner, 2012; 2015). Intentional binding has been shown to be affected in a number of disorders of agency, for example schizophrenia (e.g., Voss et al, 2010) and alien limb (Wolpe et al 2014) and to be reduced in coerced action (Caspar, Christensen, Cleeremans & Haggard, 2016).

The ‘classical suggestion effect’ of hypnosis is the experience of involuntariness of an action (Weitzenhoffer, 1980) and changes in the sense of agency are central to hypnotic responding (Polito, Woody & Barnier, 2013). Sense of agency may arise from the integration of internal, and external, predictive and retrospective cues (Moore & Fletcher, 2012; Synofzik, Vosgerau & Voss, 2013), and also general beliefs about agency. Indeed, retrospectively manipulating beliefs about agency can alter attributions of agency (Wegner, 2002). Hypnotic involuntariness may therefore reflect a relatively strong weighting of beliefs about hypnosis, and a relatively weak weighting of the internal signals provided by motor intentions.

However, highly hypnotisable participants might merely *report* that a hypnotically suggested movement feels involuntary– even though they may *experience* the action as similar to any other voluntary action. If so, phenomena sensitive to conscious intentions, such as intentional binding, should be normal following hypnosis. Alternatively, if movement under hypnosis represents a shift from relying on internal action signals to relying on experimenter-delivered beliefs about action, then implicit measures sensitive to the experience of intentional action might be altered in hypnosis for highly hypnotisable subjects. It has been shown that beliefs about whether or not one is the cause of an outcome influence intentional binding (Desantis et al, 2011). Here, we address for the first time whether binding is influenced by beliefs about whether or not an action was intended.

Method

Participants

Eighteen participants (4 males, mean age = 20.2, *SD* = 2.35) were selected for high score on the SWASH, a modified version of a standard test of hypnotisability, the Waterloo-Stanford Group Scale of Hypnotic Suggestibility, Form C (WSGC; Bowers, 1993). As requested by the reviewers, later a second group of 14 participants were selected for a medium score on the SWASH (4 males, mean age = 23.4, *SD* = 5.2). The SWASH (Sussex Waterloo susceptibility to hypnosis scale) is a modified, ten item version of the WSGC:C, with age regression and dream suggestions removed to avoid participants becoming absorbed in negative experiences (Cardeña & Terhune, 2009). In addition to the objective ratings of the WSGC:C, the SWASH also includes a subjective experience rating for each suggestion. For example, the following is the subjective rating for item 2, “Moving hands together”:

You were next told to hold your hands out in front of you about a foot apart and then told to imagine a force pulling your hands together. On a scale from 0 to 5, how strongly did you feel a force between your hands, where 0 means you felt no force at all and 5 means you felt a force so strong it was as if your hands were real magnets?

Participants were selected on the basis of their combined hypnotisability score (the simple mean of the objective and subjective scores, each scaled out of a maximum of 10), with a minimum cut-off of 5 (which was the top 11% of 266 screened) for the highly hypnotisable group. The medium hypnotisable group scored below 5 and above 2 on the SWASH. (15% of SWASH scores lie below 2).

To assess whether participants were able to maintain an experience of involuntariness for the duration of the task, verbal ratings of involuntariness on a scale between 0 (completely voluntary) and 5 (completely involuntary) were recorded after each block of trials. Seven participants from the highly hypnotisable group who reported full voluntariness (an involuntariness score of 0) after any block in the post-hypnotic involuntariness condition were excluded. Two of these participants did not complete all conditions, and therefore provided insufficient data for comparisons. As the aim was to determine an objective correlate (intentional binding) of reported feelings of involuntariness, only cases where there were feelings of involuntariness are relevant for the high hypnotisable group. Analyses of the results for all highly hypnotisable participants together (whether or not they were able to sustain the experience of involuntariness) are shown in Table S4 in the Supplemental Material available online. The combined hypnotisability score of those unable to sustain the suggestion was lower 5.98 (*SD* = 1.11) than those who maintained involuntariness, 7.48 (*SD* = 1.24), $t(16) = 2.61$, $p = .019$, $B_{H[0,2]} = 7.37$ (*B* calculated using a half-normal distribution with SD based on half the difference between the combined hypnotisability score of the first group and ten, the maximum hypnotisability score possible). The medium hypnotisable group had a mean combined hypnotisability score of 3.19 (*SD* = 0.88). None of the participants in the medium hypnotisable group were able to sustain an experience of involuntariness throughout the experiment. One participant from the highly hypnotisable group was excluded because the standard deviation of their baseline action judgements was more than 3 times the group interquartile range in the passive (614.9 ms) and post-hypnotic (470.2 ms) conditions. Therefore, data from ten highly hypnotisable participants (1 male, mean age = 20, *SD* = 1.9) are reported.

Highly hypnotisable participants were recruited for the duration of two terms, until the participant pool was exhausted. Medium hypnotisable participants were recruited during the summer break, until there were no more responses. Bayesian analyses were used to assess sensitivity. Crucially, we used Bayesian analyses to indicate the strength of evidence for H1 versus H0; the measure of evidence is valid no matter what the stopping rule (Rouder, 2014; Schoenbrodt, Wagenmakers, Zehetleitner, & Perugini, in press).

No power analysis was conducted. We included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1. Once the data are in, power has no relevance to how sensitive the data are, because power is a property of decision rule in the long run; conversely Bayes factors indicate the sensitivity of the very data collected to distinguish H1 and H0.

Ethical approval was received from the University of Sussex ethics committee and informed consent was obtained. Participants received cash payment of £18 or course credits.

Materials and methods

Visual stimuli were displayed at 100 Hz on a 21" CRT monitor and auditory stimuli were presented via Sennheiser headphones. For each trial, a clock face was presented, marked at thirty degree intervals and subtended a visual angle of five degrees. A static dot, subtending at 0.2 degrees, appeared at a pseudo-randomized position and began rotating around the clock 250 ms later (at 2560 ms per revolution). Participants were seated at a viewing distance of approximately 60 cm. A computer keyboard was used to record actions (button presses).

Each session began with a hypnotic induction adapted from the WSGC:C (included in the Supplemental Material available online). Following the hypnotic induction, participants were given the suggestion that their finger would move involuntarily onto the key for blocks of trials which followed a handclap from the experimenter. Participants were then ‘counted out’ of hypnosis before performing the experimental task. There were three counterbalanced conditions. In the voluntary condition, participants pressed the key when they wished. In the involuntary condition, the participant’s index finger was pulled onto the key by the experimenter by a fabric loop, with the experimenter’s action out of the participant’s view. A single handclap was made in the post-hypnotic suggestion condition approximately 20 seconds before the start of each 35 trial block (except the baseline tone condition). Participants were asked to rate the involuntariness of the action in each condition on a scale from 0 to 5 after each block in each condition and, additionally, after three trials of the first block of the post-hypnotic condition. No handclaps were delivered in the voluntary or involuntary conditions. Participants were informed during the hypnotic induction that the post-hypnotic suggestion would be removed when they left the room at the end of the session.

There were four trial types, presented in separate blocks. In contingent trials, pressing a key triggered a 1000 Hz, 100 ms duration tone after a 250 ms delay. Participants were asked to look at a fixation cross in the centre of the clock and to wait for at least one revolution before pressing the button at a time of their choosing. The trial was restarted if the action occurred before one full revolution or after six revolutions. Participants were asked not to plan ahead or to aim for a particular point on the clock and to report either the action or the tone (to give contingent action or contingent tone judgements). Baseline action trials were the same as contingent action trials except the button did not trigger a tone. In baseline tone trials, the tone was triggered pseudo-randomly between 2.5 s and 7 s following one revolution of the clock.

Following the tone (or action on baseline action trials), the dot continued moving for a pseudo-randomised period of time between 1200 ms and 2370 ms. The clock was then removed from the screen for a pseudorandomised time interval (500 ms to 1280 ms). When the clock reappeared, participants were able to control the position of the dot using a mouse and were asked to position the dot at the position at which it had been at the time of the judged event (action or tone) and to press the mouse button to record their judgement.

Each block consisted of 35 repetitions of one trial type except for baseline tone trials, for which 13 repetitions were taken in each condition and subsequently combined into a single block of 39 trials. The baseline tone trials were spread across the conditions in this way in order to minimise the experimental duration and reduce the possibility of participants becoming fatigued. As the baseline tone trials required no action to take place, the different experimental conditions should not influence these timing judgements. Blocks were separated by 30 s rest periods and presented in counterbalanced order. Before the session began, all participants were trained with four practice trials in the baseline tone condition and four in the baseline action condition. In order to reduce the effects of fatigue, the experimental task was split across two experimental sessions, with two conditions performed in the first session and one in the second. Participants were led through the hypnotic induction and count-out procedure at the start of each session. Sessions took place on separate days or following a gap of at least 2 hours. In total, the sessions took approximately 2 hours and 30 minutes, including training and debriefing. All Stimuli were generated with Matlab running Psychtoolbox v3.

Analysis

Mean judgement errors were calculated for each group on each trial type. Individual judgements more than 3.5 SD from the mean for each participant on each judgement type were then excluded before mean judgement errors were calculated for each participant, as also specified in Lush, Parkinson & Dienes (2016). Twenty judgements were excluded across all participants and trials (0.52% of judgements). Baseline action and tone judgement errors were subtracted from their respective contingent conditions to calculate action and outcome binding. Outcome binding was subtracted from action binding to produce a total binding measure.

Repeated measures ANOVAs were performed for action, outcome and total binding measures. Baseline action (M) judgements and within-participant SD of baseline action judgements were also compared. Where there was evidence for violation of sphericity, Greenhouse-Geisser corrected degrees of freedom were used. Significant Fs were followed up with Fisher's LSD post-hoc comparisons.

Bayes factors (*B*) were used to assess strength of evidence for one degree of freedom effects. A *B* of above 3 indicates substantial evidence for the alternative hypothesis and below 1/3 substantial evidence for the null. Thus, all Bayes factors, B, reported here represent the evidence for H1 relative to H0; to find the evidence for H0 relative to H1, take 1/*B*. *B*s between 3 and 1/3 indicate data insensitivity (see Dienes, 2014; cf Jeffreys, 1939). Here, $B_{\mathrm{H}(0,\, x)}$ refers to a Bayes factor in which the predictions of H1 were modeled as a half-normal distribution with an SD of *x* (see Dienes, 2014); the half-normal can be used when a theory makes a directional prediction where *x* scales the size of effect that could be expected (so x can be chosen from e.g. relevant past studies). $B_{N(0, x)}$ indicates H1 was specified as a normal distribution with mean 0 and SD x (for non-directional predictions). Proposals that a shared mechanism underlies functional motor disorders (motor disorders with no known neurological cause) and hypnotic involuntariness have been made since the 19th century (for a recent review see Bell, Oakley, Halligan & Deeley (2010). Kranick et al (2013) provide an estimate of intentional binding effect size for the difference between functional motor disorder patients and healthy volunteers; the difference between groups in outcome binding was approximately half the effect found in control participants. Bayes factors for differences in each measure were therefore calculated using a half-normal distribution with SD based on half the mean in the voluntary condition. $B_{U[0,max]}$ refers to a Bayes factor in which the predictions of H1 were modeled as a Uniform distribution from 0 to max. We used this model for the rating of involuntariness which is on a scale from 0 to 5; thus the maximum that the population mean difference between conditions could be was 5. A Bayes factor for the regression of the difference in outcome binding between voluntary and post-hypnotic conditions on reported involuntariness in the post-hypnotic suggestion condition was calculated using a half-normal distribution with SD based on the quotient of the mean outcome binding in the medium group (as an independent estimate of the rough amount of binding that could exist in highs) and the range of the involuntariness rating scale (i.e. 120/6). Bayes factors for simple interactions between two conditions and group were calculated modeling H1 using half the mean binding in both groups for the relevant binding component.

Predictions

We tested highly hypnotisable and medium hypnotisable groups on an intentional binding task in voluntary action and in two involuntary conditions, in which the action was passive or was reported to be experienced as involuntary following a post-hypnotic suggestion (in which response occurs following hypnosis, Barnier & McConkey, 1998) of action involuntariness. As binding is sensitive to agency, binding should be strongest in the voluntary condition and weaker in passive action. If the experience of involuntariness reported in hypnotic responding by highly hypnotisable subjects reflects real changes in the experience of agency, intentional binding should also be weakened in post-hypnotically suggested involuntariness in highly hypnotisable subjects. In terms of the comparison of highly with medium hypnotisable subjects, highs compared to mediums should have a greater difference in binding between voluntary and post-hypnotic conditions, and between passive and post-hypnotic conditions; no prediction is made for highs being different from mediums in the difference between voluntary and passive conditions.

Results

Involuntariness ratings.

Table 1 shows mean involuntariness ratings for each group in each condition. The effects of hypnotisability on reported involuntariness were analysed using hypnotisability (high vs medium) as a between-subjects factor and condition (voluntary action vs post-hypnotically suggested involuntariness vs passive action) as a within-subject factor. Importantly, there was a significant interaction between condition and group on reported involuntariness, F (1, 22) = 50.85, p < .001, η^2p = .698. The interaction was decomposed into the simple effect of condition for each hypnotisability group. For the highly hypnotisable group, there was a significant effect of agency condition on involuntariness, F(2, 18) = 135.2, p <.001, η^2p = .94. Compared to voluntary action, participants reported more involuntariness in the passive action, p <.001, $B_{U[0,5]}$ = 3.84 x 10^{28}, 95% CI [-4.98, -3.62], dz = 5.53, and post-hypnotic conditions, p <.001, $B_{U[0,5]}$ = 3.53 x 10^{11}, 95% CI [-3.62, -2.23], dz = 3.01. However, passive actions were reported to be more involuntary than actions performed following a post-hypnotic suggestion of involuntariness, p <.001, $B_{U[0,5]}$ = 2.15 x 10^8, 95% CI [.99, 1.76], dz = 2.53. For the medium hypnotisable group, there was a significant effect of agency condition on involuntariness, F(2, 26) = 413.08, p <.001, η^2p = .97. Compared to passive action, participants reported less involuntariness in the voluntary action condition, p <.001, $B_{U[0,5]}$ = 6.95 x 10^{125}, 95% CI [-5.00-, -4.28], dz = 7.33. There was evidence for no difference between voluntariness ratings in the voluntary and post-hypnotic conditions, p >.250, $B_{U[0,5]}$ = .10, 95% CI [-.53, .24], dz = .22. Passive actions were rated as more involuntary than actions performed following a post-hypnotic suggestion of involuntariness, p <.001, $B_{U[0,5]}$ = 2.43 x 10^{84}, 95% CI [4.06, 4.94], dz = 5.92.

Total binding.

Analyses of the total binding measure are reported in the online supplemental material

Outcome binding.

Table 2 shows the binding measures in each condition for both groups and Table 3 shows *p* values, Bayes factors, 95% confidence intervals and effect size for post-hoc comparisons for each main effect. The effects of hypnotisability on outcome binding were analysed using hypnotisability (high or medium) as a between-subjects factor and condition (voluntary action, post-hypnotically suggested involuntariness or passive action) as a within-subject factor. There was a significant main effect of condition on outcome binding, $F_{corrected}(1.42, 31.30) = 10.30$, $p = .001$, $\eta^2p = .319$, but no significant main effect of hypnotisability on this measure, $F(1, 22) = .929$, $p > .250$, $\eta^2p = .041$. There was a marginally significant interaction between condition and group on outcome binding, $F_{corrected}(1.42, 31.30) = 2.81$, $p = .091$, $\eta^2p = .11$. The theory that hypnotic response is experienced as passive predicts two key partial interactions. Specifically, there was, as predicted, an interaction between group and voluntary vs post-hypnotic conditions on outcome binding, $F(1,22) = 9.18$, $p = .006$, $B_{H(0, 62.5)} = 39.01$, $\eta^2p = .29$. There was no evidence one way or the other for an interaction between passive and post-hypnotic conditions, $F(1,22) = .222$, $p > .250$, $B_{H(0, 62.5)} = .67$, $\eta^2p = .01$. Finally there was no sensitive evidence for an interaction between group and voluntary vs passive conditions on outcome binding, $F(1,22) = 3.52$, $p = .074$, $B_{N(0, 62.5)} = 1.63$, $\eta^2p = .14$. The planned simple effect of condition for the highly hypnotisability group revealed a significant effect of agency on outcome binding, $F_{corrected}(1.15, 10.37) = 5.50$, $p = .037$, $\eta^2p = .38$. Compared to voluntary action, outcome binding was lower for both the passive action and post-hypnotic conditions. For the medium hypnotisable group, there was also a significant effect of agency on outcome binding, $F(2, 24) = 5.52$, $p = .010$, $\eta^2p = .30$. Compared to passive action, outcome binding was higher for voluntary and post-hypnotic action. There was sensitive evidence for no difference in outcome binding between the voluntary and post-hypnotic conditions.

Action binding.

The effects of hypnotisability on action binding were analysed using hypnotisability (high or medium) as a between-subjects factor and condition (voluntary action, post-hypnotically suggested involuntariness or passive action) as a within-subject factor. There was no significant main effect of condition on action binding, $F(2, 44) = .579$, $p > .250$, $\eta^2p = .026$, nor was there a significant effect of group, $F(1, 22) = 1.165$, $p > .250$, $\eta^2p = .050$. The interaction between condition and group on action binding was also not significant, $F\ (2, 44) = .579$, $p > .250$, $\eta^2p = .03$. The more precise partial interactions were all non-evidential; no conclusions follow. Specifically, there was only insensitive evidence for the interaction between group and voluntary vs post-hypnotic conditions on action binding, $F(1,22) = .859$, $p > .250$, $B_{H(0, 19)} = 1.19$, $\eta^2p = .038$; the same for the interaction between group and voluntary and passive conditions on action binding, $F(1,22) = .013$, $p >.250$, , $B_{N(0, 19)} = .68$, $\eta^2p = .001$; and for the interaction between group and passive vs post-hypnotic conditions, $F(1,22) = .623$, $p >.250$, $B_{H(0, 19)} = 1.22$, $\eta^2p = .03$. The planned simple effect of condition for the highly hypnotisability group was not significant, $F(1.30, 11.72) = .032$, $p > .250$, $\eta^2p = .004$. While the action binding shifts in the voluntary condition for highly hypnotisable participants are comparable to other reported results (e.g., 20 ms reported in Haggard, Clark & Kalogeras, 2002), we found no sensitive evidence for a difference in action binding between conditions to parallel the shift in outcome binding. However, as can be seen in Table 2, neither is there is substantial evidence for no difference between any two conditions; the data are simply insensitive and provide support for neither the experimental or null hypothesis. We can therefore draw no conclusions about action binding based on the results of this study. The insensitivity is not surprising; as we found, outcome binding is typically a bigger effect than action binding (e.g. Desantis, Roussel & Waszak, 2011; Kranick et al, 2013; Lush, Parkinson & Dienes, 2016). Given that action binding is characterised by a smaller shift than outcome binding, a larger sample might be required to reveal differences in this measure.

Figure 1 shows the derived interval between the action and tone events in each condition. As outcome binding was reduced but not eliminated in passive actions, these results are broadly consistent with evidence that intentional binding is a special case of a general causal binding (Buehner, 2012). As passive actions were reported to be more involuntary than post-hypnotically induced involuntariness for highly hypnotisable subjects, we should expect a difference in magnitude of binding between these two conditions. Table 2 shows that the mean values follow this expected pattern. However, as the comparisons between these two conditions are insensitive, we can draw no firm conclusions about this pattern of results (table 3).

To investigate the relationship between the experience of involuntariness and binding, regression analysis of the difference in outcome binding between voluntary and post-hypnotic suggestion conditions over reported involuntariness in the post-hypnotic condition was conducted. All medium and highly hypnotisable participants (including those excluded from other analyses because they were unable to maintain involuntariness) were included in this analysis.

Reported involuntariness predicted the difference in outcome binding between voluntary and post-hypnotic conditions, the raw slope being 19 ms/rating unit, $t(27) = 2.37$, $p = .025$, $B_{H(0, 20)} = 6.48$. Therefore, outcome binding was reduced in the post-hypnotic condition compared to the voluntary condition as reported involuntariness increased, supporting the hypothesis that binding difference is related to subjective experience.

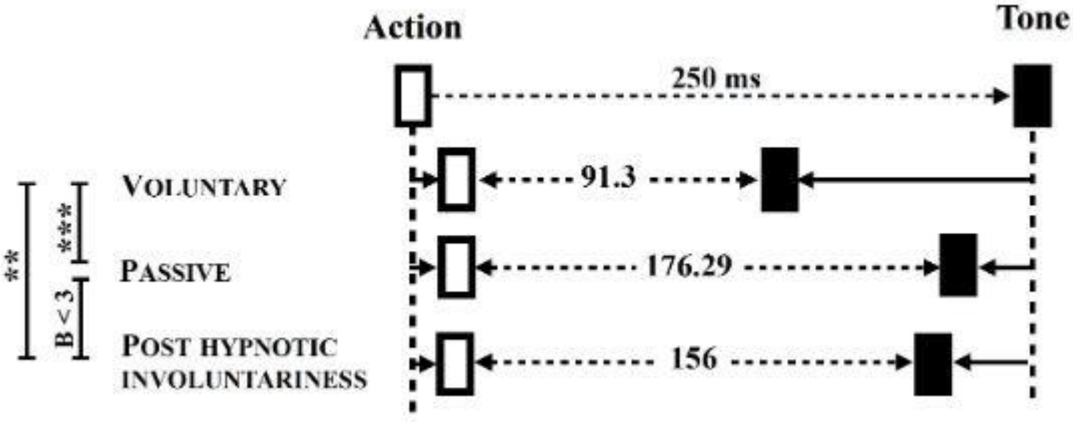

Figure 1. Derived time intervals between action and tone events in the highly hypnotisable group: ** = 3 <B <10, *** = B >10

Group (hypnotisability)		Condition		
		Voluntary	Post-hypnotic involuntariness	Passive
High				
	Involuntariness rating	.7 (.30)	3.3 (.17)	5 (0)
Medium				
	Involuntariness rating	.3 (.16)	.4 (.20)	4.9 (.07)

Table 1. Mean (SE) involuntariness ratings in each group. 0 = completely voluntary, 5 = completely involuntary.

Group (hypnotisability)		Condition		
		Voluntary	Post-hypnotic involuntariness	Passive
High				
	Action binding	28.0 (25.0)	24.6 (56.7)	23.2 (53.7)
	Outcome binding	-130.7 (45.4)	-69.4 (56.0)	-50.51 (89.1)
Medium				
	Action binding	9.9 (28.2)	25.6 (38.4)	3.1 (42.9)
	Outcome binding	-120.2 (66.3)	-117.9 (67.9)	-83.5 (79.7)

Mean times are given in ms (SD).

Table 2. Mean binding for the high and medium hypnotisable groups in the three experimental conditions

		Comparison		
Group)		Voluntary action vs passive action	Voluntary action vs Post-hypnotic suggestion	Passive action vs post-hypnotic suggestion
High				
	Action binding	p > .250 $B_{\mathrm{H}(0, 14)}$ = .91 [-29.3, 38.8] dz = 0.10	p > .250 $B_{\mathrm{H}(0, 14)}$ = .89 [-32.9, 39.7] dz = 0.07	p > .250 $B_{\mathrm{H}(0, 14)}$ = .93 [-59.4, 56.8] dz = 0.02
	Outcome binding	p = .003* $B_{\mathrm{H}(0, 65)}$ = 79.51** [-124.4, -35.9] dz =1.08	p = .009* $B_{\mathrm{H}(0, 65)}$ = 14.70** [-103.4, -19.2] dz = 0.93	p > .250 $B_{\mathrm{H}\ 0, 65)}$ = .76 [-59.0, 96.8] dz = 0.17
Medium				
	Action binding	p > .250 $B_{\mathrm{H}(0, 5)}$ = 1.08 [-16.8, 30.5] dz = .17	p > .250 $B_{\mathrm{H}(0, 5)}$ = .77 [-44.3, 12.8] dz = .31	p = .121 $B_{\mathrm{H}(0, 5)}$ = 1.33 [-52.0, -6.9] dz = .43
	Outcome binding	p = .019* $B_{\mathrm{H}(0, 60)}$ = 7.07** [-66.4, -7.0] dz = .67	p > .250 $B_{\mathrm{H}(0, 60)}$ = .22** [-23.5, 18.8] dz = .063	p = .022* $B_{\mathrm{H}\ 0, 60)}$ = 6.11** [-62.8, -5.9] dz = .65

** Significant at the .05 level. ** Sensitive B (> 3 or < 1/3). Brackets show 95% CIs*

Table 3. Post-hoc comparisons between each condition in the high and medium hypnotisable groups.

Discussion

Replicating previous studies, causal binding in voluntary action was stronger than in passive action (Haggard, Clark & Kalogeras, 2002; Buehner, 2015). Crucially, binding was also reduced in high hypnotisables after a post-hypnotic suggestion of involuntariness, providing evidence for hypnotically induced changes in sense of agency.

We only found evidence for changes in outcome binding. The prediction of the sensory outcome of an action may provide cues for sense of agency by comparing a predicted sensory outcome to the actual outcome and hypnotic suggestion may disrupt this mechanism by preventing motor intentions from activating sensorimotor predictions (Blakemore, Oakley & Frith, 2003). Therefore, reduced outcome binding may arise from disruption to a comparator preventing sensorimotor pre-representation of an action outcome.

An alternative account proposes that, by analogy with cross-modal cue combination (Ernst & Banks, 2002; Körding et al, 2007), the timing judgements of intentional actions and their outcomes may be a weighted average of the action and outcome cues (Kawabe, Roseboom & Nishida, 2013), with the weighting dependent on the estimated precision with which each is individually timed. The decreased outcome judgement shift reported here may therefore arise from the increased weighting of the outcome cue over the action cue in estimating the time of the outcome event when motor intention information is discounted and the estimated precision of the action cue consequently decreases (consistently, in the online supplemental material we report lower within-participant SD in the voluntary than in the post-hypnotic condition for high hypnotisables and sensitive evidence of no difference in medium hypnotisables).

This would occur in passive action because motor intention information is absent, and in post-hypnotic involuntariness because hypnotist induced beliefs reduce the relative weighting of motor intentions in generating sense of agency. A cue combination mechanism is predictive of an increase in action binding when motor intention information is reduced, as lower precision of action should result in a relatively higher weighting of the outcome cue in outcome timing judgements and consequently a greater shift of the weighted average of the two events toward the action cue. This might run contrary to our prediction of reduction in overall binding, as the two opposing shifts would, to at least some degree, cancel each other out. However, as we report no sensitive evidence for differences in action binding, the results of the current study do not bear on this prediction either way.

While the current study is the first to show the relevance of beliefs about intentions to binding, outcome binding is also reduced when participants incorrectly believe that an outcome is triggered by another's action (Desantis, Roussel & Waszak, 2011). This may reflect a reduced contribution of motor intentions to outcome timing judgements when, according to beliefs, such information is not relevant to event timing. Binding has also been shown to be reduced when participants are instructed to press a particular key at a particular time (Caspar et al 2016). By contrast, in the current study, participants were free to press the button when they wished and were merely instructed that they would not feel that they had intended the action.

It might be argued that hypnotic responding occurs in the absence of intentions (e.g. Woody & Bowers, 1994). However, given hypnotic actions are performed in appropriate and flexible ways, intentions appear undisrupted in hypnotic responding, and it is the metacognition of intentions that is disrupted (e.g. see Woody & Sadler, 2008). Thus, the difference between hypnotic and non-hypnotic action may lie in the awareness of intentions (Dienes, 2012; Lush, Naish & Dienes, 2016). If so, an intention being conscious may increase its availability to other processes (Cleeremans & Jiménez, 2002), and thus to the process of timing its associated action. Consistently, mindfulness meditators, who may have more accurate metacognition of motor intentions (Dreyfus, 2011), show stronger outcome binding (Lush, Parkinson & Dienes, 2016). It should be noted that highly hypnotisable people are a highly selected group, and these results may not generalise to the general population.

We report that hypnotically suggested actions behave more like genuinely involuntary than voluntary actions in an implicit measure sensitive to agency, providing objective evidence for hypnotically suggested changes in agentic experience and demonstrating that beliefs about whether an action is intended influence binding.

Chapter V

Intentional binding in trait hypnotisability

Abstract

An experience of involuntariness is central to hypnotic responding, and may arise from an ability to sustain inaccurate metacognition of first-order intentions. Trait differences in the ability to respond to hypnotic suggestion may reflect differing levels of access to motor intentions, with highly hypnotisable people having relatively low access and low hypnotisable people greater access. Intentional binding refers to the subjective compression of the time between an action and its outcome, typically indicated by a forward shift in the judged time of an action toward its outcome (action binding) and the backward shift of an outcome toward the action that caused it (outcome binding). The effect is considered an implicit measure of the sense of agency as it is sensitive to intentional action without explicit reflection upon agency. Intentional binding may represent a simple case of multisensory cue combination. Following such an interpretation, increasing the variance of an action or its outcome should decrease the bias of the perceived timing of one cue toward another. Here we present results consistent with such a mechanism. The results support the theory that trait hypnotisability is related to access to information related to motor intentions. In a contingent presentation of action and outcome events, lows reported less variable timing judgements of actions than highs and less variable timing judgements of action events than of outcome events within-group. Lows also showed weaker action binding than highs, and weaker action than outcome binding within-group. Intentional binding may reflect the combination of cross-modal cues based on an ontogenetically acquired casual prior.

Introduction

The sense of agency (SoA) is the experience we have of controlling our actions and their outcomes (Moore, 2016; Haggard, 2017). Research on SoA can measure explicit judgements of agency, such as asking whether or to what degree a particular action or outcome is associated with an experience of agency (e.g., Wegner & Wheatley, 1999). Alternatively, implicit measures which require no reflection upon agency can be used, of which the intentional binding effect is perhaps the most commonly employed. Intentional binding refers to the compression of the perceived interval between the reported times of actions and their outcomes (Haggard, Clark & Kalogeras, 2002). Intentional binding is considered to be an implicit measure of sense of agency because the effect is reduced or even extinguished in unintended actions (for reviews see Moore & Obhi, 2012; Wolpe & Rowe, 2014). However, temporal binding of actions and outcomes also occurs in the timing of events which are merely observed when a causal relationship is inferred, so intentional binding is perhaps best described as the effect of motor intention-related information on the magnitude of temporal binding over and above causal binding (Buehner, 2012; 2015).

Intentional binding can be measured by deriving intervals between the reported time of an action and outcome event from the difference in the reported time of the events when the outcome is contingent upon the action (contingent conditions) and when it is not (baseline conditions). Timing judgements can be made using a Libet clock method (e.g., Libet, 1985) in which participants report the position of a rapidly moving clock hand when an event is perceived. Measured in this way, intentional binding can be seen to consist of two opposing shifts in reported time from baseline to contingent conditions: action timing judgements towards the time of the outcome event (action binding) and outcome timing judgements toward the time of the action event (outcome binding). This temporal binding between an action and its outcome may arise from a cue combination mechanism, in which the timing estimate reported for either action or outcome events is a precision weighted average of the two events (Kawabe, Roseboom & Nishida, 2013; Wolpe, Siebner & Rowe, 2013). Such a mechanism predicts that a relatively high precision of event timing should have opposing effects on binding components. For example, relatively high precision of action event timings will result in both action and outcome event timing judgements which are relatively close to the action, so that the magnitude of action binding will be relatively small and that of outcome binding relatively large. Conversely, if precision of action event timing judgements is relatively low, there will be reduced outcome binding and greater action binding. Therefore, individual differences in the availability of motor intention-related information which affects the relative precision of action timing judgements should be reflected in intentional binding.

Hypnosis is fundamentally related to changes in the experience of agency, and the experience of involuntariness has been described as the classical suggestion effect of hypnosis (Weitzenhoffer, 1980). According to dissociated experience theories of hypnotic responding, the experience of involuntariness in hypnotic responding occurs when monitoring systems become dissociated from cognitive control systems (for a review, see Woody & Sadler, 2008). According to higher order thought (HOT) theories of consciousness, conscious experiences are essentially metacognitive; a particular mental state only becomes conscious when there is a higher order mental state directed at it (Rosenthal, 2000). The cold control theory of hypnosis recasts dissociated experience within the framework of HOT theory, arguing that the experience of hypnotic involuntariness arises from the production and maintenance of inaccurate HOTs directed at unconscious first order intentions (Dienes, 2007; 2010). Therefore, a successful response to a hypnotic suggestion involves performing an intentional act but, through an inaccurate HOT of intending, experiencing the act as unintentional. The sense of agency may be generated by the integration of multiple sources of information, with the influence of each source weighted by precision (Moore, Wegner & Haggard, 2009; Synofzik, Vosgerau & Lindner, 2009). Therefore, hypnotic responding may arise from the relatively high weighting of hypnosis-related beliefs and the relatively low weighting of motor information.

Hypnotisability can be measured by response to suggestion on standardised scales following hypnotic induction (for reviews see Laurence, Beaulieu-Prévost & Du Chéné, 2008; Terhune & Cardeña, 2016). Measured in this way, hypnotisability can be considered a relatively stable trait, with strong test-retest reliability over a 25-year period (Piccione, Hilgard & Zimbardo, 1989). According to cold control theory, individual differences in trait hypnotisability should reflect individual differences in the ability to generate and maintain inaccurate metacognition of 1st order intentions. There is some recent evidence which supports the theory that an ability to generate and sustain an experience of involuntariness reflects a trait for relatively low access to 1st order intentions. High hypnotisables report later awareness of motor intention than medium or low hypnotisables (Lush, Naish & Dienes, 2016) and are less sensitive to disruptions of control when forming judgements of agency in a task designed to measure metacognition of SoA (Terhune & Hedman, 2017). There is also evidence that the classical suggestion effect is related to a reduction of action intention related information in timing judgements; a post-hypnotically induced experience of involuntariness is accompanied by less anticipatory judgements of action timing (Haggard & Oakley, 2004), and, in intentional binding, by an increase in the variability of action timing judgements and a reduction in outcome binding (Lush et al, 2017).

Here we investigate the relationship between trait hypnotisability and intentional binding. We draw on evidence for a relationship between hypnotisability and metacognition of intentions and assume a cue combination model as the mechanism of binding to form predictions. We predict that lower metacognitive access to 1st order intentions in high hypnotisables will be reflected in increased within-participant variance of action timing judgements and consequently reduced outcome binding and increased action binding. We make the opposite predictions for low hypnotisables; increased metacognitive access to 1st order representations of intending will be reflected in more precise within-participant action timing judgements and, consequently, decreased action binding and increased outcome binding.

Method (adapted from Lush, Parkinson & Dienes, 2016)

Participants

Forty participants were recruited following screening on the Sussex Waterloo Scale of Hypnotisability (SWASH; in prep). Of these, 18 participants were highly hypnotisable (3 males and 15 females, mean age = 19.3 years, *SD* = 2.3) and 22 low hypnotisable (2 males and 20 females, mean age = 20.9 years, *SD* = 2.3)

Combined subjective and objective hypnotisability scores (the simple mean of the objective and subjective scores, each scaled out of a maximum of 10) were used to identify high and low hypnotisables participants, with a minimum cut-off of 5.5 (which was the top 10% of 418 screened) for the highly hypnotisable group (*M* = 6.5, *SD* = .8) The low hypnotisable group (*M* = 1.3, *SD* = .6) scored below 2 (15% of SWASH scores lie below 2).

Ethical approval was received from the University of Sussex ethical committee and informed consent was obtained. Participants received cash payment of £7 or course credits.

As in Lush et al (2017), participants were recruited for the duration of six terms, until there were no more responses.

Procedure (adapted from Lush, Parkinson & Dienes, 2016)

Visual stimuli were displayed at 100 Hz on a 21-in. CRT monitor and auditory stimuli were presented via Sennheiser headphones. For each trial, a clock face was presented, marked at thirty degree intervals and subtended a visual angle of five degrees. A static dot, subtending at 0.2°, appeared at a pseudo-randomised position and began rotating around the clock 250 ms later (at 2560 ms per revolution). Participants were seated at a viewing distance of approximately 60 cm. A computer keyboard was used to record actions (button presses).

There were four trial types, presented in separate blocks. In contingent trials, pressing a key triggered a 1000 Hz, 100 ms duration tone after a 250 ms delay. Participants were asked to look at a fixation cross in the centre of the clock and to wait for at least one revolution before pressing the button at a time of their choosing. The trial was restarted if the action occurred before one full revolution or after six revolutions. Participants were asked not to plan ahead or to aim for a particular point on the clock and to report either the action or the tone (to give contingent action or contingent tone judgements). Baseline action trials were the same as contingent action trials except the button did not trigger a tone. In baseline tone trials, the tone was triggered pseudo-randomly between 2.5 s and 7 s following one revolution of the clock.

Following the tone (or action on baseline action trials), the dot continued moving for a pseudo-randomised period of time between 1200 ms and 2370 ms. The clock was then removed from the screen for a pseudorandomised time interval (500 ms to 1280 ms). When the clock reappeared, participants were able to control the position of the dot with a mouse. Moving the mouse forward (toward the screen) caused the dot to move in a clockwise direction around the clock face and the reverse mouse movement (away from the screen) caused the dot to move counter-clockwise around the clock face. Participants were asked to move the dot to the position it had occupied at the time of the judged event (action or tone) and to press the mouse button to record their judgement.

Each block consisted of 40 repetitions of one trial type and blocks were separated by 30 s rest periods. The four blocks were presented in counterbalanced order.

Before the session began, all participants were trained with four practice trials in the baseline tone condition and four in the baseline action condition so that they could become familiarised with the reporting procedure. All Stimuli were generated with Matlab running Psychtoolbox v3 (Kleiner et al., 2007)

Measures

Within-participant SD of timing judgements provides a measure of precision in estimating the time of an event. If binding reflects the combination of cues according to the precision afforded to actions or their outcomes, any differences in intentional binding should be accompanied by differences in this measure. In terms of cue combination theory, it is the interaction between high vs low hypnotisables by outcome vs action timing precision that determines changes in intentional binding between groups.

Mean judgement errors were calculated for each group on each trial type. Individual judgements more than 3.5 SD from the mean for each participant on each judgement type were excluded before mean judgement errors were calculated for each participant. Thirty-four judgements were filtered by this method (2.1 % of all trials). The adjusted mean errors for action and tone conditions were then subtracted from their respective contingent conditions to calculate action and outcome binding. If binding reflects cue combination, an interaction between high vs low hypnotisables by action and outcome timing precision should be reflected in an interaction between high and low hypnotisables and action vs outcome binding.

Data analyses

Bayes factors (*B*) were used to assess strength of evidence (Wagenmakers Verhagen Ly Matzke Steingroever Rouder & Morey, 2017). Unlike null-hypothesis significance testing, Bayes factors have the advantage of distinguishing sensitive evidence for H0 from not much evidence at all. A *B* of above 3 indicates substantial evidence for the alternative over the null hypothesis and below 1/3 substantial evidence for the null over the alternative hypothesis. *B*s between 3 and 1/3 indicate data insensitivity in distinguishing null and alternative hypotheses (Dienes, 2014; Jeffreys, 1939). Here, $B_{H[0,\, x]}$ refers to a Bayes factor in which the predictions of H1 were modelled as half-normal distribution with a mean of 0 and an SD of x (Dienes 2014); the half-normal can be used when a theory makes a directional prediction where x scales the size of effect that could be expected (so x can be chosen from e.g. relevant past studies).

Kranick et al. (2013) provide an estimate of the sort of difference in intentional binding that could be found between different groups using conversion disorder patients; the difference between groups in tone binding was on the order of magnitude of about half the effect found in control participants. Bayes factors for group differences in each measure were therefore calculated using a half-normal distribution with SD based on half the average of action and outcome binding in all participants.

Bayes factors for within-participant SD of timing judgement group contrasts were calculated using a half-normal based on the expected change in variance accompanying a 50% change in binding. On the theory that binding arises from the Bayesian combination of outcome and action time estimates, the percentage change in binding would equal the percentage change in the relative precision, i.e. of the variance; the change in SD should be proportionate to the square root of the change in variance. Thus, a 50% change in variance amounts to the standard deviation changing to 0.7 of its value, i.e. a reduction of 30%.

Results

Baseline within-participant SD of event judgements

First, we tested the prediction that highly hypnotisable participants would have less precise reports of baseline action event timing judgements than lows, but that the two groups would not differ in precision of reports of baseline tone event timing judgements. There was no evidence either way for an interaction, $F(1, 38) = 1.44$, $p = 0.238$, $B_{H[0, 16]} = 1.33$, $\eta^2p = .036$ (see figure 1). Planned simple effects comparisons showed that high hypnotisables had greater variability of baseline action timing judgements (M = 76.4ms, SD = 24.3) than low hypnotisables (M = 58.3 ms, SD = 19.2), $t(38) = 2.64$, $p = .012$, $d = .83$, $B_{H[0, 16]} = 14.29$. There was no evidence either way for a difference between baseline tone judgement SD in highs (M = 89.2 ms, SD = 22.8) and lows (M = 80.2 ms, SD = 16.9 ms), $t(1,38) = 1.42$, $p = .163$, $d = .45$, $B_{H[0, 16]} = 1.59$. High hypnotisables had lower SD when timing actions than outcomes, $t(17) = 1.85$, $p = .082$, $dz = .44$, $B_{H[0, 16]} = 3.23$, and low hypnotisables also had less variable judgements of action than of outcome in baseline conditions, $t(21) = 5.41$, $p < .001$, $dz = 1.16$, $B_{H[0, 16]} = 323302.46$.

Contingent within-participant SD of event judgements

Next, we tested the same prediction for SD of reports of timing judgements when the outcome tone was contingent upon the action event. There was evidence for an interaction, $F(1, 38) = 3.38$, $p = .074$, $B_{H[0, 16]} = 3.37$, $\eta^2p = .082$ (see figure 2).

Planned simple effects analyses revealed that high hypnotisables showed greater variability in contingent action judgements (M = 88.4ms, SD = 34.6), than low hypnotisables (M = 61.9 ms, SD = 19.26), $t(25.40) = 2.91$, $p = .007$, Glass's $\Delta = .77$, $B_{H[0, 16]} = 35.79$. There was no evidence either for or against the prediction that there would be no difference in within-participant SD of contingent tone judgements between highs (M = 91.9 ms, SD = 22.5) and lows (M = 83.9 ms, SD = 27.35), $t(1, 38) = .984$, $p = .331$, $d = .32$, $B_{H[0, 16]} = .1.07$. There was no sensitive evidence for whether or not highs varied in SD between contingent action and outcome judgements, $t(17) = .486$, $p = .633$, $dz = .12$, $B_{H[0, 16]} = .60$. Low hypnotisables however, did have less variable judgements of action than of outcome in contingent conditions, $t(21) = 3.09$, $p = .005$, $dz = .95$, $B_{H[0, 16]} = 46.34$.

Action and outcome binding

Finally, we tested the prediction that as a result of having relatively lower access to motor intentions, high hypnotisables would have increased action binding and decreased outcome binding. There was marginal evidence for an interaction between group and type of event judged (action or outcome) on timing judgement shift from baseline, $F(1,14) = 3.25$, $p = .080$, $B_{H[0, 24]} = 2.82$, $\eta^2p = .079$. Figure 3 shows the action and outcome binding measures for each group. t-tests were used to test planned comparisons between groups and on each binding measure. There was evidence that highly hypnotisable participants showed a greater shift of action toward tone in contingent trials (M = 41.1 ms, SD = 36.4) than low hypnotisables (M = 22.6 ms, SD = 27.2), $t(38) = 1.84$, $p = .073$, $d = .58$, $B_{H[0, 24]} = 3.11$. There was no evidence as to whether low hypnotisables showed a greater shift of tone toward action in contingent trials (M = -77.69 ms, SD = 70.7) than high hypnotisables (M = -51.27 ms, SD = 82.4), $t(38) = 1.09$, $p = .282$, $d = .34$, $B_{H[0, 24]} = 1.49$. While there was no evidence for whether or not action binding differed from outcome binding in highs ($t(17) = .466$, $p = .647$, $dz = .12$, $B_{H[0, 16]} = .91$, low hypnotisables showed less action binding than outcome binding, $t(21) = 3.09$, $p = .001$, $dz = 1.02$, $B_{H[0, 16]} = 359.73$.

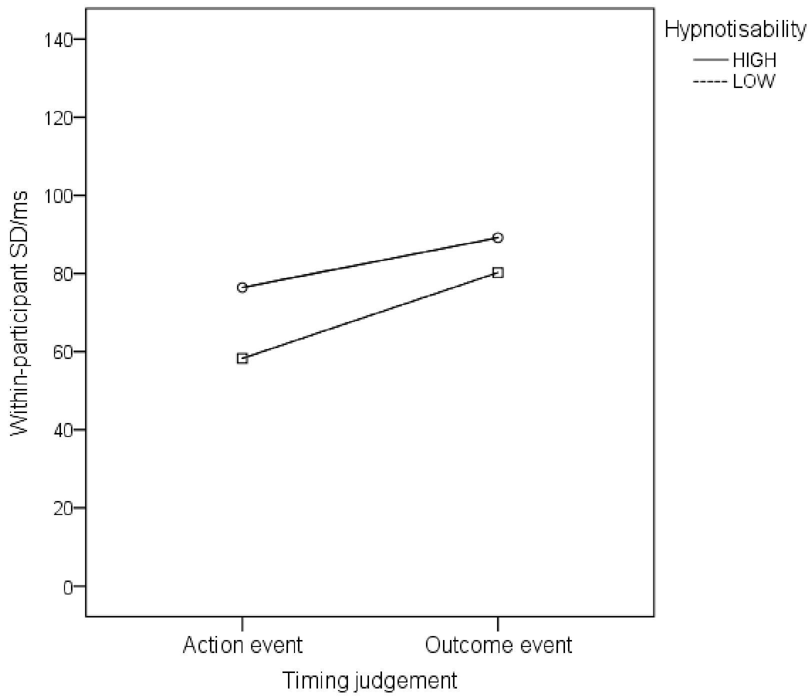

Figure 1. Interaction between high and low hypnotisability and judged event on baseline condition within participant standard deviations of timing judgements.

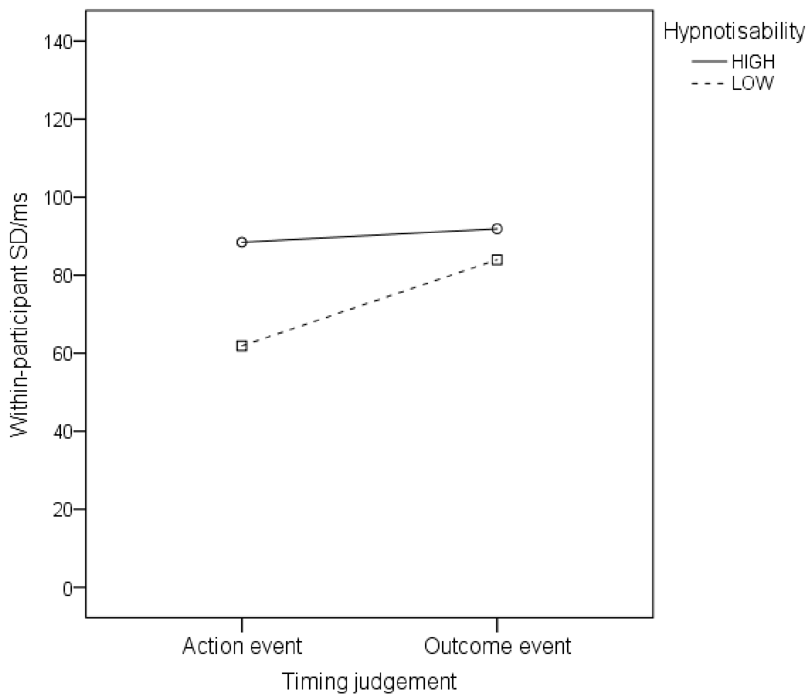

Figure 2. Interaction between high and low hypnotisability and judged event on contingent condition within participant standard deviations of timing judgements.

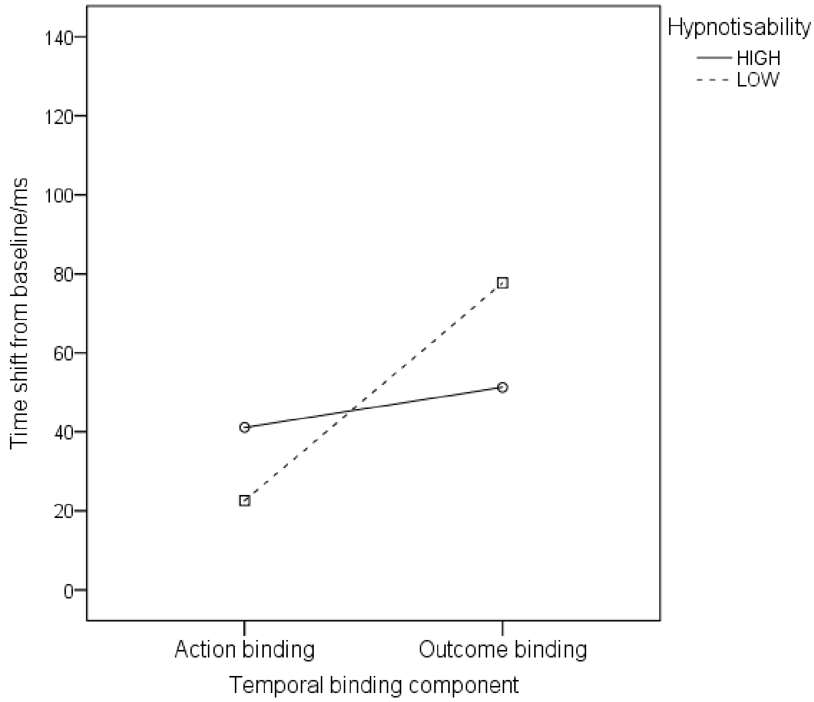

Figure 3. Interaction between high and low hypnotisability and judged event on contingent condition timing shift from baseline

Discussion

We tested high and low hypnotisable participants in an intentional binding task. Low hypnotisables showed reduced action binding compared to outcome binding both within-group and when compared to high hypnotisables. Lows also reported less variable judgements of the time of an intentional action than highs, and less variable within-group timing of action than outcome events. These results are consistent with both a cue combination model of intentional binding and of a relationship between trait differences in hypnotisability and metacognition of intentions. There was no sensitive evidence either for or against the hypothesis that lows would show more outcome binding than highs, so no firm conclusions can be drawn regarding outcome binding in trait hypnotisability.

According to a cue combination model, when precision of action timing judgements is high there should be a relatively small shift of action timing towards the outcome event and a relatively large shift of outcome event timing towards the action. Both high and low hypnotisables showed less variable action timing judgements than they did outcome judgements. However, we should expect that relatively precise information about the timing of an action event (compared to an outcome event) is available to the initiator of an action (Moore & Fletcher, 2012), and crucially, the magnitude of this difference was smaller than that of lows.

There is direct experimental evidence for a cue combination mechanism supporting action binding. Wolpe, Siebner & Rowe (2013) manipulated the variability of outcome judgements by masking the outcome tone with varying levels of white noise and found that action binding decreased when outcome judgements were relatively imprecise. However, to date no direct evidence for or against cue combination in outcome binding has been published. It has been proposed that outcome binding may occur when the threshold for perception of an action outcome is crossed more rapidly due to a sensorimotor prerepresentation of the outcome. However, there is evidence against action outcome identity playing a role in intentional binding (for a review see Hughes, Desantis & Waszak, 2013).

There is evidence for differences in action binding in disorders of agency. In corticobasal syndrome (for which disorders of agency are diagnostic), patients show greater action binding than controls and the magnitude of action binding is positively related to variability of action time judgements (Wolpe et al, 2014b). Because the patient group showed abnormalities in a brain area considered important for motor intentions (the preSMA), these results may be attributable to differences in access to motor intentions. Additionally, Voss et al (2010) report greater action binding in schizophrenic patients than in controls (although no evidence for a difference in action timing variability was reported for this study).

Increased within-participant variance of action timing judgements in high hypnotisables relative to low hypnotisables is consistent with the theory that trait hypnotisability reflects differences in metacognitive access to 1st order intentions (Dienes 2010; Dienes et al, 2016; Lush, Naish & Dienes, 2016). High hypnotisables may show greater variance in action timing judgements because they have less access to motor intention related information when forming HOTs of intending. Consistent with this, highs show more variable action judgement timing (and decreased outcome binding) following a post-hypnotic suggestion for the experience of involuntariness over actions (Lush et al, 2017). There is also evidence that TMS of dorsolateral prefrontal cortex (dlPFC) increases hypnotisability (Dienes & Hutton, 2013). The dlPFC has been proposed to support HOTs (Lau & Rosenthal, 2011; Passingham & Wise, 2012) (including HOTs of intending, Lau, Rogers, Haggard & Passingham, 2004), so the increase in hypnotic responding may be attributable to the disruption of HOTS of intending. If dlPFC supports HOTs relevant to precision of action timing judgements, disruption of dlPFC should lead to an increase in action timing variability, reduced action binding and increased outcome binding.

It has been argued that the sense of agency arises from the integration of multiple sources of information, with the influence of each source weighted by precision (Moore, Wegner & Haggard, 2009, Synofzik, Vosgerau & Lindner, 2009). Therefore, hypnotic responding may arise from the relatively high weighting of hypnosis-related beliefs and the relatively low weighting of motor information. It should be noted that, according to cue integration models of SoA, the relationship between intentional binding and SoA is not straightforward. For example, having relatively low outcome binding does not mean that highs differ in their sense of agency because when information from one source is weak, other information will be weighted more highly (Moore & Fletcher, 2012). Consistent with this argument, when performing an intentional binding task in which the predictability of an outcome is manipulated (Moore & Haggard, 2008), schizophrenic patients have been shown to rely more on external, retrospective cues than on internal predictive signals (e.g., motor intentions) compared to controls (Voss et al 2010). If hypnotisability involves trait differences in access to information about motor intentions, we should expect to see a similar pattern in highs using this paradigm.

As high and low hypnotisables are both special groups, it has been argued that medium hypnotisables should be included as a control group in hypnosis studies, to distinguish between the possibilities that the difference is attributable to highs or lows alone (Kirsch, 2011). This study was based on evidence for a linear relationship between hypnotisability and metacognition of intentions (Dienes, 2015; Lush, Naish & Dienes, 2016), and the inclusion of low hypnotisables maximized the predicted potential differences. However, future studies are required to rule out the possibility that the relationships between trait hypnotisability and variance of action judgements or components of binding are non-linear.

In summary, we report reduced precision of action timing judgements and increased action binding in high compared to low hypnotisables. These results are consistent with a cue combination model of intentional binding and with the theory that hypnotisability is related to differences in the availability of motor intention related information.

Chapter VI

The Sussex-Waterloo Scale of Hypnotisability

Abstract

The ability to respond to hypnotic suggestibility (hypnotisability) is a stable trait which can be measured in a standardised procedure consisting of a hypnotic induction and a series of hypnotic suggestions. The SWASH is a 10-item adaptation of an established scale, the Waterloo-Stanford Group C Scale of Hypnotic Suggestibility (WSGC). Development of the SWASH was motivated by three distinct aims: to reduce required screening time, to provide an induction which more accurately reflects current theoretical understanding, and to supplement the objective scoring with experiential scoring. Screening time was reduced by shortening the induction, removing two suggestions which may cause distress (dream and age regression) and by modifications which allow administration in lecture theatres, so that more participants can be screened simultaneously. Theoretical issues were addressed by removing references to sleep, absorption and eye fixation and closure. Data from 418 participants at the University of Sussex and the University of Lancaster are presented, along with data from 66 participants who completed a re-test screening. The subjective and objective scales were highly correlated. The subjective scale showed good reliability, and objective scale reliability was comparable to the WSGC. The addition of subjective scale responses to the post-hypnotic suggestion (PHS) item suggested a high probability that responses to PHS are inflated in WSGC screening. The SWASH is an effective measure of hypnotisability, which presents practical and theoretical advantages over existing scales.

Introduction

Hypnosis involves reliable changes in experience which present a unique opportunity for experimentally investigating consciousness. In particular, the experience of involuntariness in central to hypnotic responding (Weitzenhoffer, 1980). Hypnosis is an effective tool for experimentally investigating alterations in the sense of agency or the experience of voluntary action (Haggard & Oakley 2004; Lush et al, 2017); thus, it creates illusions in agentic consciousness. Additionally, many highly hypnotisable people can experience vivid hallucinations or other altered sensory experiences; thus, hypnosis creates illusions in perceptual consciousness. That is, hypnosis can be used instrumentally for investigating a wide range of conscious experiences (Cardeña, 2014; Terhune, Cleeremans, Raz & Lynn, 2017). However, hypnosis is under-used in comparison to established experimental methods of altering, for example, visual consciousness (e.g., continuous flash suppression; Tsuchiya & Koch, 2005) or bodily self-consciousness (Lenggenhager, Tadi, Metzinger & Blanke, 2007).

Hypnotisability can be considered a stable trait (Piccione, Hilgard, and Zimbardo, 1989), and empirical investigation of hypnosis commonly employs standardised scales in order to identify potential participants. While scale administration is a straightforward process which requires little training and requires no more than the ability to read a script (Kihlstrom, 2008), established inductions are unnecessarily long and fail to reflect contemporary theoretical understanding (Terhune & Cardeña, 2017; Woody & Barnier, 2008). Here we present a revised version of an established scale, with the aim of creating a practical and theoretically relevant screening procedure which we hope will make hypnosis research more widely accessible to the consciousness research community.

The development of the Sussex-Waterloo Scale of Hypnotisability (SWASH) has been guided by several distinct aims. First, we aimed to construct a time-efficient screening procedure. Second, we wanted to remove some allusions to theories which are no longer considered to be true. Third, we wanted to include an integrated experiential scale, as although hypnosis is characterised by changes in subjective experience, hypnotisability is often measured only according to objective criteria.

The Waterloo-Stanford Group Scale of Hypnotic Susceptibility, Form C (WSGC; Bowers, 1993) is a 12-item scale adapted from the earlier SHSS:C (Weitzenhoffer & Hilgard, 1962), in which participants are screened individually. The WSGC was developed to have more difficult items than the group Harvard (Shor & Orne, 1963), which contains a relatively high proportion of easier ideomotor suggestions and therefore can fail to sufficiently identify high hypnotisables (Bowers, 1993; Laurence, Beaulieu-Prévost, & Du Chéné, 2008).

Woody and Barnier (2008) proposed a four facet model for hypnotic suggestions in standardised scales, with items categorised as either direct or challenge suggestions which require either a motor or perceptual-cognitive response, and the WSGC contains a representative mix of these suggestion types. However, the WSGC can be time consuming to run, as sessions are administered to group sizes of a dozen or fewer and can take up to 90 minutes to complete. Commonly, the highest and lowest scoring 10 percent of participants are identified as highly and low hypnotisable. Therefore, a large number of participants must be screened in order to obtain an acceptable sample sizes for studies which require these groups. At Sussex, screening with the WSGC typically involves approximately 900 minutes of screening to identify just 10-12 highly hypnotisable participants. In constructing the SWASH, our primary aim was to reduce the time necessary to establish a participant pool while retaining the difficult items used by the WSGC and the SHSS:C, so that people at the high end of hypnotisability can be still identified.

We reduced screening time in two ways. First, session length was reduced by editing the WSGC induction and by reducing the number of suggestions. Second, the WSGC was modified for increased group size. We will first address the steps taken to decrease screening session time, and then the modification necessary for large group presentation.

The common theme in hypnotic inductions is that they establish a hypnotic context for the period of time in which suggestions are delivered (Lynn, Maxwell & Green, 2017; Sheehan & Perry, 1976). There is evidence that the increase in response to suggestion attributable to hypnotic induction is small (Braffman & Kirsch, 1999; see Connors, Barnier, Coltheart et al, 2012, for an exception), and that any increase in responding over non-hypnotic suggestibility may be attributable to the use of the word "hypnosis" (Gandhi & Oakley, 2005). Thus, a minimal condition for an induction to enhance response may be simply defining the context as one appropriate for hypnotic response. It is unclear exactly what else, if anything, may be needed to constitute a minimal context, but as there is evidence for very brief inductions being less effective (Klinger, 1970), we aimed to cut the induction to only around half its original length.

While evidence for effects on responding is mixed (for a review see Terhune & Cardeña, 2016) the prevalence of relaxation instructions in hypnotic inductions suggest that a requirement for relaxation might be expected by many and therefore be useful for establishing the hypnotic context (Lynn, Maxwell & Green, 2017). Therefore, and although relaxation is not a necessary component of hypnotic inductions (Banyai & Hilgard, 1976; Cardeña, 2004), we retained elements of the WSGC relating to relaxation and counting down in order to ensure the induction was long enough to meet participants' possible expectations.

All direct references to sleep were removed from the induction script, as hypnosis is distinct from sleep (Hull, 1933). However, some references to tiredness were retained as part of the relaxation procedure. An analogy between hypnosis and inattention to the environment whilst driving was also removed, as being distracted or absorbed is not the same as hypnotic responding (the correlation of hypnotisability with absorption is about 0.3 and usually is not found if tested out of the hypnotic context; Laurence, Beaulieu-Prévost, & Du Chéné, 2008). Finally, eye fixation and closure (the Braid effect; Weitzenhoffer, Gough & Landes, 1959) is a feature of most hypnotic inductions, but there is evidence that it does not increase suggestibility (Weitzenhofer & Sakata, 1970). As a substantial proportion of the WSGC induction is related to eye closure, the removal of this material considerably shortened the induction. In total, the pre-suggestion induction script (including preliminary instructions) was cut from 1636 words to 873 words.

Screening time was further reduced by the removal of two perceptual-cognitive WSGC suggestions: dream and age regression. There have been reports of negative responses to the age regression suggestion (Cardeña & Terhune, 2009), and the dream suggestion also involves highly personalised experiences that may be negative (Hilgard, 1974). The WSGC contains a disproportionately high number of perceptual-cognitive suggestions (Woody & Barnier, 2008), so these items could be dropped without leaving this facet underrepresented. Further, the average score on these two items matches that of the WSGC overall (age regression 6.1, Dream 4.4 = 5.3, mean WSGC = 5.8; Bowers, 1993), so the removal of these items does not change the level of difficulty of the scale as a whole. The SWASH therefore contains ten suggestions: two motor (hand lowering;

moving hands together), two motor challenge (arm rigidity; arm immobilisation), three perceptual-cognitive (mosquito hallucination; music hallucination; taste hallucination), two perceptual-cognitive challenge (amnesia; negative visual hallucination) and a post-hypnotic suggestion to draw a tree but to forget the instruction, which combines a direct motor suggestion with a perceptual cognitive challenge (Woody & Sadler, 2008).

With these adjustments, the total time to administer the SWASH is around 40 minutes rather than approximately 90. Because it can be administered to more people simultaneously (it has been tested with up to 50) establishing a participant pool with the WSGC should take almost 10% of the time required by the WSGC.

The negative visual hallucination suggestion was modified for large group presentation. The WSGC negative hallucination suggestion involves placing three coloured balls in the centre of the room. In the SWASH, a picture of three coloured balls are presented on a slide. Some minor modifications to other suggestions were made to improve universality (in particular for non-native English speakers). Baseball and billiard ball were replaced by bowling ball for the arm heaviness suggestion and Jingle Bells was replaced by Happy Birthday for the music hallucination, as it is perhaps the most widely recognised song worldwide (Brauneis, 2010).

The WSGC relies on behavioural scoring to generate a pass or fail score for each item. However, it is not the visible physical responses to suggestion but the experience which accompanies the suggested behaviour which is of particular interest in hypnotic responding. A subjective scale has been developed for the WSGC (Kirsch, Milling & Burgess, 1998), but unfortunately has received little attention from researchers. The SWASH subjective scale is similar to this existing scale, with responses to questions regarding the veridicality of the suggested experience recorded on a scale between 0 and 5.

The SWASH differs from the earlier scale in requiring two subjective responses to the post-hypnotic suggestion (PHS) item. The PHS in the Harvard Group Scale of Hypnotic Susceptibility, Form A (HGSHS:A; Shor & Orne, 1962) requires participants to touch their ankles following a signal but not to remember doing so. Sadler & Woody (2004) have criticised objective scoring of this item on the basis that it cannot exclude ‘spurious passes’ that include actions experienced as voluntary and with full memory of the suggestion. Similarly, the WSGC PHS suggestion is passed if participants draw a tree in their booklet. However, the suggestion states that participants will draw a tree but forget that they were told to do so. For the SWASH, therefore, a PHS response only receives a subjective score if participants report both an urge to draw a tree and some amnesia about hearing the suggestion. We anticipate that this approach is likely to identify a substantial number of spurious passes for this item.

Participants often report spontaneous experiences which occur following a hypnotic induction, and such effects have previously been measured by subjective ratings of hypnotic ‘depth’ (e.g., Tart, 1970). As such depth ratings can correlate with response to suggestion, it has been suggested that induction depth could act as a proxy measure of hypnotisability (Wagstaff, Cole & Brunas-Wagstaff, 2008). We included such a rating of depth in order to investigate this possibility and as a check that the edited induction produced hypnotic depth experiences.

The purpose of this study was to produce a more efficient version of the WSGC, measuring hypnotisability across the range of ability, potentially opening hypnosis research up to a greater number of researchers who might otherwise be put off by the impracticalities of screening.

Method

Participants

Four-hundred and twenty-nine participants were recruited to undergo a hypnotic screening procedure at the University of Sussex or at Lancaster University. Eleven participants were excluded for incomplete data, so data from 418 participants (331 female, 87 male) were analysed, of which 331 participated at the University of Sussex. The mean age of participants was 19.9 years (*SD* = 4.0). Participants at the University of Sussex were invited to return for a retest screening approximately two months after their initial screening and retest data was recorded for 66 participants. Psychology student participants received course credits, and no other compensation was offered.

Materials

An induction and suggestion script was adapted from the WSGC (Bowers, 1998). Participants recorded their responses in a booklet adapted from the WSGC. This contained subjective responses on a scale from 0 to 5. There were two versions of the booklet used. The second booklet differed from the first only in the addition of anchoring labels at each end of the scale used to record each subjective response. Approximately half of the participants completed each booklet, with 206 participants completing booklet 1 and 212 completing booklet 2. For the repeat screening, 59 participants completed booklet 2 on both occasions and 6 completed booklet 1.

A slide containing a picture of three coloured balls (green, blue and red) presented in a triangular formation on a black background was projected onto a screen at the front of the lecture theatre during the screening.

Procedure

Participants were screened in a lecture theatre in groups of up to 50 and were instructed to leave a seat free between them and the next participant in order to allow freedom for arms to move (e.g. during the magnetic hands suggestion). A slide instructing participants to turn off their mobile phones was displayed, along with information about the length of the procedure. Before the session began, participants were instructed to fill in the front of the booklet with their personal information and then to sit back in their chair. The experimenter then thanked participants for their attendance and introduced his or her self and informed participants how long the procedure would take before reading from the script. The script contained a brief introductory passage and an induction.

Analyses

Mean objective and subjective scores were calculated. The scores for each version of the booklet were compared for objective and subjective scales. Data from the two booklets were then combined for subsequent analyses.

Objective scores were scored according to the WSGC booklet (Bowers, 1998). Subjective scores were taken on a 0-5 scale for each item. For example, for item 2, moving hands together the following instruction was given for subjective response: "On a scale from 0 to 5, how strongly did you feel a force between your hands, where 0 means you felt no force at all and 5 means you felt a force so strong it was as if your hands were real magnets?"

For two suggestions, there were two subjective responses requested. For 'taste' these were about the experience of 'sweet' and 'sour' suggestions and for the post-hypnotic suggestion item there were questions relating to experienced urge and to amnesia.

Objective scale scores between 0 and 10 for each participant were calculated by summing the successful objective responses for that participant. Subjective scale scores between 0 and 5 were calculated from the average of subjective scale responses. The final subjective response score for taste is the mean of the sweet and sour responses. For the post-hypnotic suggestion, the geometric mean of the urge and amnesia responses for the item was calculated, so that a subjective response for this item would be zero if either of the components of the suggestion did not generate a subjective response.

An additional measure of induction depth was taken: “On a scale from 0 to 5, to what degree did you enter a hypnotic state, where 0 means your general state of consciousness was just the same as normal, 1 means you were slightly hypnotized and 5 means you entered very deep hypnosis?”

Scale validity was investigated by correlation analysis of subjective and objective scales, point biserial correlations between objective and subjective responses for each item and by comparison with data for the SWASH item responses from a 2014 WSGC screening of 202 participants.

Reliability of objective and subjective scales was checked with coefficient omega, an alternative to Cronbach’s alpha which overcomes some of alpha’s known deficiencies (Dunn, Baguley & Brunsden, 2014). Reliability was further examined by calculating the omega coefficient when each SWASH suggestion was dropped on each scale, the corrected same scale item-total correlations and test-retest correlations.

To investigate how well the induction depth rating reflects the subjective and objective scales, correlations between strength of induction and each scale/item were run.

95% Confidence Intervals are reported throughout, which can be interpreted as 95% Credibility Intervals with uniform priors.

Results

Scores

Objective scores on booklet 1 were very similar to scores on booklet 2, with a mean difference in score of 3.70 vs 3.61 = .09 (*SE* = .18), 95% CI [-26, .44]. Subjective scores across the two booklets were also similar, with a mean difference in score of 3.44 vs 3.28 =.17 (*SE* = .16), 95% CI [-15, .48]. There was a difference in correlations between objective and subjective scores across the two booklets of just .71 vs .68 = .03, 95% CI [-.07 0.13]. Therefore, results from the two booklets were combined. Mean score out of ten on the objective scale was 3.7 (*SD* = 1.8) and mean subjective score out of five was 1.7 (*SD* = .8).

Validity

There was a correlation between objective and subjective scales, *r*(418) = .70, 95% CI [.65, .75], providing support for the validity of the subjective scale. Table 1 shows mean subjective score and point biserial correlations between objective and subjective responses for each item. Objective and subjective responses were all at least moderately correlated, (with a mean coefficient of .46) except for the post-hypnotic suggestion to draw a tree. The subjective response for this item was calculated as the geometric mean of a participant's responses to two questions: the first about their urge to draw a tree and the second about amnesia for the suggestion. While urge to draw correlated with objective response, *r*(418) = .54, 95% CI [.47, .60], there was no evidence for a correlation between objective response and amnesia for the suggestion, *r*(418) = -.09, 95% CI [-.18, .01]. The urge and amnesia questions also did not correlate with each other, *r*(418) = .01, 95% CI [-.09, .11]

Suggestion	M	SD	r_{pb}
1. Hand lowering	3.4	1.3	.46 [.38, .53]
2. Moving hands together	2.9	1.4	.33 [.24, .41]
3. Mosquito hallucination	1.0	1.4	.65 [.59, .70]
4. Taste hallucination*	1.4	1.3	.65 [.59, .70]
5. Arm rigidity	2.7	1.5	.57 [.50, .63]
6. Arm immobilisation	2.3	1.5	.44 [.36, .51]
7. Music hallucination	.23	.7	.56 [.49, .62]
8. Negative visual hallucination	.43	1.1	.49 [.41, .56]
9. Amnesia	1.4	1.3	.34 [.25, .42]
10. Posthypnotic suggestion**	.93	1.4	.14 [.04, .23]

*All correlations significant at p< .001 except ** for which p = .04.*

Table 1. Mean subjective score and point biserial correlations between behavioural and experiential scoring of suggestions

Table 2 shows percentage of objective suggestions passed on the 2013 WSGC run at Sussex and the SWASH from 2014-2016. Scores are comparable between SWASH and Sussex except for negative hallucination, PHS and amnesia.

Suggestion	SWASH	WSGC
1. Hand lowering	71.8	77.2
2. Moving hands together	76.8	76.7
3. Mosquito hallucination	26.1	27.7
4. Taste hallucination*	30.9	29.7
5. Arm rigidity	54.9	68.3
6. Arm immobilisation	36.4	46.5
7. Music hallucination	5.0	5.9
8. Negative visual hallucination	9.3	21.8
9. Amnesia	14.6	5.9
10. Posthypnotic suggestion**	39.5	24.3

Table 2. Comparison of Sussex 2013 WSGC and SWASH percentage of participants passing each suggestion on the objective criterion

Reliability

Omega for the objective scale was 0.53, 95% CI [.44, .60], suggesting that internal consistency was not high for this scale. For the subjective scale, omega was considerably higher, .83 (*SE* = .013) 95% CI [.80, .85], indicating good internal consistency for this scale (for comparison, Cronbach's alpha point estimates were .52 for objective and .82 for subjective scales). 2014 WSGC data at Sussex also had low reliability, with omega .56, 95% CI [.46, .66] for all 12 WSGC suggestions and omega = .47, 95% CI [.31, .57] for the WSGC with just the ten items shared with the SWASH included.

Table 3 shows omega coefficient if the item is dropped for each SWASH suggestion on each scale. Point estimates of the coefficient were lower in all cases on the subjective scale. However, omega was slightly higher for post-hypnotic suggestion.

	Objective omega	Subjective omega
1. Hand lowering	.52 [.44, .60]	.81 [.78, .84]
2. Moving hands together	.52 [.44, .53]	.82 [.79, .85]
3. Mosquito hallucination	.49 [.41, .57]	.82 [.79, .84]
4. Taste hallucination	.46 [.37, .54]	.81 [.77, .83]
5. Arm rigidity	.44 [.33, .53]	.80 [.77, .83]
6. Arm immobilisation	.50 [.41, .57]	.80 [.77, .83]
7. Music hallucination	.52 [.44, .59]	.82 [.80, .85]
8. Negative visual hallucination	.50 [.42, .57]	.83 [.80, .85]
9. Amnesia	.51 [.48, .61]	.81 [.78, .84]
10. Posthypnotic suggestion	.55 [.48, .61]	.82 [.79, .84]

Table 3. OMEGA (if item dropped) (95% CI in brackets)

Table 4 shows item-total correlations. Each item was correlated with the corrected total scale score. However, while item-total correlations for the subjective scale were substantial (mean r = .51), the objective scale item-total correlations were on average small (mean r = .22).

	Objective *r*	Subjective *r*
1. Hand lowering	.19 [.10, .28]	.53 [.46, .60]
2. Moving hands together	.20 [.11, .29]	.48 [.40, .55]
3. Mosquito hallucination	.24 [.15, .33]	.50 [.42, .57]
4. Taste hallucination	.32 [.23, .40]	.59 [.52, .65]
5. Arm rigidity	.36 [.27, .44]	.61 [.55, .67]
6. Arm immobilisation	.23 [.14, .32]	.62 [.56, .68]
7. Music hallucination	.12 [.02, .21]	.34 [.25, .42]
8. Negative visual hallucination	.25 [.16, .34]	.35 [.26, .43]
9. Amnesia	.18 [.09, .27]	.55 [.48, .61]
10. Posthypnotic suggestion	.11 [.01, .20]	.57 [.50, .63]

Table 4. Corrected same scale item-total correlations for objective and subjective scores (95% CI in brackets).

Test/re-test reliability

Objective score on retest, (M = 4.0, SD = 2.0), was not strongly correlated with the original objective score of those taking part in the retest (M = 3.7, SD = 2.0), $r(66)$ = .56, 95% CI [.37, .71]. However, there was a strong correlation between mean re-test subjective score, M = 3.1 (SD = 1.9) and the original subjective score of those taking part in the retest M = 3.4, (SD = 1.6), $r(66)$ = .77, 95% CI = [.65, .85].

Objective return score correlated highly with subjective return score, $r(66)$ =.81, [.71, .88].

Induction correlations

Mean induction rating was 2.3 (*SD* = 1.1). The induction rating correlated with the objective score, $r(418) = .44$, 95% CI [.36, .51] and with the subjective score $r(418) = .62$, 95% CI [.56, .68].

Table 5 shows correlations between induction depth score and individual items on each scale. All subjective items significantly correlated with the induction depth. For the objective scale, all items except music and post-hypnotic suggestion correlated with induction.

	Objective	Subjective
1. Hand lowering	.24 [.15, .32]	.47 [.39, .54]
2. Moving hands together	.12 [.02, .21]	.43 [.35, .51]
3. Mosquito hallucination	.16 [.07, .25]	.34 [.25, .42]
4. Taste hallucination	.34 [.25, .42]	.43 [.35, .51]
5. Arm rigidity	.29 [.20, .38]	.47 [.39, .54]
6. Arm immobilisation	.17 [.08, .26]	.42 [.34, .50]
7. Music hallucination	.06 [-.04, .16]	.21 [.12, .30]
8. Negative visual hallucination	.19 [.10, .28]	.25 [.16, .34]
9. Amnesia	.22 [.13, .31]	.45 [.37, .52]
10. Posthypnotic suggestion	.07 [-.03, .16]	.32 [.23, .40]

Table 5: Correlations between induction depth score and individual items on each

Discussion

We tested participants on the Sussex-Waterloo Scale of Hypnotisability (SWASH), a modified version of the Waterloo-Stanford Group Scale of Hypnotic Susceptibility. The subjective scale of the SWASH showed good reliability and objective scale reliability was comparable to that of the WSGC. Although the study design does not allow us to disentangle any particular element of the induction, we report no evidence for a substantial decline in scores over the WSGC. We suggest, therefore that, a simple relaxation procedure with counting down and repeated use of the word hypnosis is sufficient to generate response to hypnotic suggestions comparable to the WSGC.

We found good reliability for the subjective scale, but not for the objective scale. It is not surprising that a scale based on ratings outperforms one based on dichotomous items. We therefore suggest recruiting for experiments using either the subjective score or a combined objective and subjective score. For example, one could take the simple mean of the two scores (with the subjective score multiplied by two to be on a 0-10 scale), as we report in Lush, Naish & Dienes, 2016.

The strength of the correlation between objective and subjective SWASH scales indicates that the subjective scale is a valid measure of hypnotisability. However, the post-hypnotic suggestion item showed only a weak correlation between objective and subjective responses. This issue arose as a result of breaking the subjective response to this item down into the two components of the suggestion: urge to perform the action and amnesia for the suggestion. While there was a relationship between successfully responding to the suggestion on the objective criterion (by drawing a tree) and reporting an urge to respond, relatively few participants who drew a tree reported amnesia for the suggestion. This suggests that post-hypnotic suggestions scored solely on objective criteria produce an unacceptably high level of false positives. In our sample, more than half of the objective passes to the PHS suggestion did not pass the subjective criteria. If only those reporting a high level of amnesia (4-5 on the subjective scale) are included, the pass rate is less than 5%, or (2.1% for full amnesia). It is therefore likely that the rate of successful post-hypnotic responding has been over-estimated in previous WSGC samples (and indeed screens from other scales). As researchers routinely recruit for hypnosis experiments based on overall scores on a scale, this systematic confound is likely to have resulted in a substantial number of falsely inflated hypnotisability scores. As Sadler & Woody (2004, p.151) have argued, the continued use of unmodified PHS suggestions "represents a triumph of tradition over science".

Objective scale SWASH pass rates were numerically low compared to the WSGC for negative visual hallucination and for challenge suggestions, and numerically high for post hypnotic suggestion and amnesia; overall similar means were reported for both scales, the population difference likely being no larger than 0.46.

According to Weitzenfoffer (1980), the experience of involuntariness is what distinguishes a hypnotic response from a voluntary action. Here, we employed a subjective scale of veridicality as this may be an indirect index of the experience of involuntariness (people experience e.g., hallucinations as real because they don't experience their intention in generating the experience; Dienes, 2007). However, given the centrality of the experience of involuntariness to hypnotic responding, future scales might benefit from the inclusion of a scale which directly taps this experience. Using scales developed for the SHSS: C, Bowers (1981) reported that 20% of responses considered successful by behavioural criteria were not accompanied by the classical suggestion effect and P. Bowers (1988) that 20% of failed responses were accompanied by reports of the experience if involuntariness. However, directly asking questions about involuntariness may not be straightforward as for certain suggestions they can be confusing for participants (Kirsch & Braffman 2001) and reported changes in sense of agency may reflect different underlying factors (Polito, Barnier & Woody, 2013).

In summary, the Sussex Waterloo Scale of hypnotisability is an effective instrument for measuring hypnotisability. The scale offers considerable practical and theoretical advantages over existing scales which tap a similarly wide range of hypnotic experience. The procedure can be administered to large groups of participants in a lecture hall setting and completed well within the time period of a typical lecture. It therefore can be employed to rapidly establish a participant pool for hypnosis-related research. We hope that it makes hypnosis studies practical for researchers interested in investigating the reliable experimental manipulation of conscious experience.

Chapter VII

Discussion

Summary

The studies presented here investigated the theory that hypnosis and mindfulness meditation are related in opposing ways to metacognition of intentions; metacognition of intentions is disturbed in hypnotic responding and mindfulness meditation involves the development of metacognition, including of intentions (Dienes et al, 2015). Evidence relating to hypnosis was presented in Chapter II, Chapter IV and Chapter V and evidence relating to Mindfulness meditation was presented in Chapter II and Chapter III. Chapter VI presented norms for a new hypnotisability scale: the Sussex-Waterloo scale of hypnotisability (SWASH).

Metacognition of intentions

First I will discuss the evidence presented here as it relates to metacognition of intentions. Chapter II, Chapter IV and Chapter V describe data consistent with the theory that hypnosis is related to metacognition of intentions and Chapter II and Chapter III the theory that mindfulness meditation improves metacognition. In Chapter II, it is shown that trait hypnotisability is related to a later time of an intention to move. This is consistent with the cold control theory of hypnosis; to respond to a hypnotic suggestion is to act voluntarily whilst forming and maintaining an inaccurate higher order thought about that intention (Dienes, 2008; 2010). Such inaccurate metacognition requires that information related to the intention is given low weighting in the generation of a HOT of intending. Therefore, reports of delayed experience of motor intentions in high hypnotisables may reflect the relative inaccessibility of motor intention-related information to higher cognitive processes. Conversely, mindfulness meditators reported earlier awareness of motor intentions. This may reflect relatively high accessibility of metacognitive ability arising from sustained mindfulness practice (Repetti, 2010; Dreyfus, 2013).

Chapters III, IV & V relate metacognition of intentions in hypnosis to intentional binding: the perceived compression of the time interval between an intentional action and its outcome (which is generally considered to be an implicit measure of the sense of agency; Haggard, Clark & Kalogeras, 2002). In Chapter III, we report that a post-hypnotic suggestion (PHS) of involuntariness over actions leads to changes in sense of agency as measured by both explicit verbal judgements of agency and by an implicit measure of the sense of agency (intentional binding). Compared to voluntary action, the backward shift of outcome timing judgements towards the time of the action (outcome binding) was reduced in highly hypnotisable participants who reported a PHS-induced experience of involuntariness over their action whilst performing the task. Outcome binding was not reduced in medium hypnotisable participants, who did not report a PHS-induced experience of involuntariness over their actions. As intentional binding is sensitive to agency (for a review see Moore & Obhi, 2012), this reduction in binding suggests intention-related information is reduced in judgements of action timing during an experience of hypnotic involuntariness. The reduction of outcome binding in highs was accompanied by an increase in the variability of action judgements and an increase in variability of action judgements is suggestive of a decrease in the availability of motor-intention related information for timing judgements and an intention being conscious may increase its availability to other cognitive processes (e.g., Cleeremans & Jiménez, 2002). So, the results presented in Chapter IV are consistent with the predictions of cold control theory.

Trait differences in hypnotisability are reflected in outcome binding and variability of baseline action judgements in a manner consistent with cold control theory (Chapter V), providing support for the argument from cold control that trait hypnotisability reflects trait differences in accessibility of intentions. Conversely, mindfulness meditators show greater outcome binding and less variable baseline action judgements than non-meditators (Chapter III), and therefore may have improved metacognitive access to intentions.

There is other recent evidence consistent with the theory that hypnotisability and mindfulness meditation are related to metacognition of motor intentions in opposing ways. In a metacognition of agency task (Metcalfe & Greene, 2007), high hypnotisables are less vulnerable than low hypnotisables to distortions in their sense of agency brought about by disruption of control (Terhune & Hedman, 2017). This finding is consistent with highs relying less on motor information than on other external cues in generating a sense of agency. Future work could test mindfulness meditators with this paradigm, with the prediction that they should be more sensitive to disruptions of control due to improved metacognition of motor intentions. It has also recently been shown that mindfulness meditation and hypnotisability are related to differences in the experience of the rubber hand illusion in a manner consistent with this theory (RHI; Botvinick & Cohen, 1998); hypnotic suggestibility correlates positively with proprioceptive drift in the RHI (Walsh et al, 2015), and mindfulness meditators are less susceptible to RHI induced distortions of the sense of agency as measured by explicit judgements of agency (Cebolla et al, 2016). Future studies could investigate other established methods for manipulating sense of agency in these groups. For example, Wegner, Sparrow & Vinermans (2004) vicarious agency task, in which the experimenter’s hands are positioned where the participant’s hands would normally be.

Older people are less susceptible to this illusion, and this may be attributable to the relatively high weighting of internal signals (Cioffi, Cocchini, Banissy & Moore, 2017; though contrast Metcalfe, Eich & Castel, 2010, in which older people, like highs, are less vulnerable to disruptions of control in a metacognition of agency task, arguably due to less precise internal information about actions). The predictions from the theory presented here are straightforward: highs should be more susceptible to this illusion, and mindfulness meditators less susceptible.

I will now briefly discuss how these results relate to hypnosis and mindfulness meditation more generally. The evidence presented in Chapter II is consistent with theoretical approaches to hypnosis in which changes in the monitoring of intact intentions drive the experience of involuntariness in hypnotic responding (e.g., cold control theories; Dienes, 2007; 2008; 2012). The evidence presented in Chapter IV is consistent with both dissociated experience and dissociated control theories (e.g. Woody & Bowers, 1994), as precision of action event timing would also be expected to decrease if an intention was disrupted at the first order level. While this might also apply to the data in Chapter V it is more likely that relatively low precision of action timing in high trait hypnotisability is attributable to trait differences in metacognition of intentions than in first order intentions (as would be the case for dissociated control theories), as a relative deficit in the ability to produce voluntary action would be likely to have wide ranging effects on high hypnotisables which would be unlikely to go unnoticed. So, taken together the evidence across studies is consistent with cold control theory.

While the evidence here is consistent with the argument that mindfulness meditation improves metacognition of intentions, Buddhist practice is multi-faceted (e.g., Rosch, 2007) and it cannot be ruled out that results could be attributable to other aspects of Buddhist practise. Furthermore, while metacognition of intentions is, arguably, a central aspect of mindfulness (Grossenbacher & Quaglia, 2017), Buddhist practice involves mindfulness of a wide variety of perceptions (e.g., Dreyfus, 2011; Kuan, 2012) and there is no reason to expect mindfulness-related differences in the formation and maintenance of HOTs to be limited to those directed at intentions. We might therefore expect meditators to also have improved metacognition other than of intentions (e.g., see Fleming & Lau, 2014). Applying other metacognitive measures to hypnotisable groups could also inform theories of hypnosis. Cold control theory does not predict domain-general changes in metacognition and evidence for a relationship between domain-general metacognition and hypnotisability would require a reassessment of the theory.

A general point that should be addressed is that the studies presented in Chapter II, Chapter III and Chapter IV are correlational, and therefore do not provide direct evidence that differences in metacognition of intentions are causally related to hypnotisability or to mindfulness meditation. For example, the work presented here relating to mindfulness meditation was motivated by the hypothesis that mindfulness practice is a form of metacognitive training. However, the reported results are merely consistent with the proposed theory that mindfulness meditation improves metacognition of intentions, rather than direct evidence for it. There is evidence for changes in various measures following brief mindfulness interventions (e.g., Zeidan et al, 2010), so such interventions may reveal mindfulness induced changes in metacognition of intentions. A longitudinal design in which meditation-naïve participants are tested on both hypnotisability and the cognitive tasks employed for this thesis before and after mindfulness training could provide direct experimental support for the theory that mindfulness meditation improves metacognition of intentions. The evidence as to whether hypnotisability can be increased by training is mixed (for reviews see Barnier & McConkey, 2004; Laurence, Beaulieu-Prévost & du Chéne, 2008). However, if the ability to respond hypnotically is related to metacognitive accessibility of first order intentions it may be relatively straightforward to reduce hypnotisability by metacognitive training. Therefore, training of metacognition of intentions through mindfulness meditation might also provide direct evidence for a causal relationship between hypnotisability and metacognition of intentions.

I will now consider the possible role of context effects in the studies presented in this thesis. A potential confound for studies investigating hypnotisability as a trait is a tendency for study participants to interpret instructions according to a hypnotic context. This is known to be problematic for questionnaire designs, as correlations between trait hypnotisability and questionnaire measures often fail to replicate once the questionnaire is administered outside of the hypnotic context (Heap, Brown, & Oakley 2004; Laurence, Beaulieu-Prévost, & Du Chéné, 2008). This may be a problem for the questionnaire measure of trait mindfulness (FFMQ-SF) used here to investigate mindfulness in trait hypnotisability, for which we report a negative correlation (Chapter II). The hypnotic context may also influence cognitive measures (Martin, Sackur & Dienes, 2017). In reporting the time of the experience of an intention to move, a participant who, for example, knows they have been recruited for a hypnosis related experiment due to their particularly high or low hypnotisability might be influenced by that knowledge. Therefore, it cannot be ruled out that some or all of the group differences in W judgements reported in Chapter II are attributable to context effects. This is perhaps less of an issue for the intentional binding experiments reported in Chapters IV and V. Intentional binding requires no introspection about agency and the predicted pattern of results would not be easy to guess. However, it cannot be ruled out that the hypnotic context drives the differences in action timing judgement variability reported here (Chapter IV, Chapter V). If binding is driven by cue combination, the differences reported here in outcome or action shift would naturally follow. Future studies of trait hypnotisability in cognitive tasks should control for this possibility by ensuring that participants are naïve to the hypnosis-related context wherever possible.

Similar issues arise when interpreting the results from mindfulness meditators in terms of metacognition of intentions. It is reasonable to assume that experienced Buddhist meditators would have certain expectations about their abilities in performing a cognitive task which might differ from those of non-meditators. It is plausible that the timing of an intention to move could be influenced by such expectations. It is also plausible that the variability of action timing judgements could be similarly influenced. However, we should also expect meditators to show reduced outcome timing variability in this circumstance. Indeed, meditators showed less variable judgements of timing for both events than non-meditators. Crucially, however, this difference was more pronounced when judging actions than outcomes (p.148).

The Sussex-Waterloo Scale of Hypnotisability

The data in Chapter VI are consistent with evidence that the effect of hypnotic inductions on response to suggestion are minimal and may be largely, if not entirely, attributable to the establishment of a hypnotic context. However, while several components historically considered important for successful hypnotic induction were removed for the SWASH induction, it might be possible to reduce the length of induction further. Future studies could directly test content and duration of inductions in order to identify the minimum induction necessary to provide a hypnotic context (Terhune & Cardeña, 2016) Besides being of empirical value, such research could further improve the practicality of hypnosis research by further reducing required screening time. Additionally, the modifications made to the SWASH for large group screening mean that only minor further adjustments would be necessary to administer the procedure by computer and potentially make large scale internet based hypnosis research viable.

Mechanisms of intentional binding

If sense of agency arises from cross-modal cue integration, then differences in intentional binding may reflect differences in the relative weighting of the action and outcome cues in sense of agency (Moore, Wegner & Haggard, 2009). Therefore, binding may result from the influence of each cue on the timing of the other, weighted by their relative precision (Kawabe, Roseboom & Nishida, 2013). While there is existing evidence that action binding arises from a cue combination mechanism (Wolpe, Haggard, Siebner & Rowe, 2013), it has been argued that outcome binding may arise when sensorimotor pre-representation of action outcomes lowers the perceptual threshold of an action outcome (Waszak, Cardoso-Leite & Hughes, 2012; Wolpe & Rowe, 2014). However, outcome binding is likely to depend on temporal control rather than sensorimotor predictions of action outcomes, as binding occurs when the identity of the action outcome is unpredictable (Desantis, Hughes & Waszak, 2012, Gethin, Desantis & Waszak, 2013, Haering and Kiesel, 2011). Furthermore, the arguments made for a dual process model are based on failures to reject the null hypothesis for differences in one of the components (e.g., Wolpe, Haggard, Siebner & Rowe, 2013; Desantis, Roussel & Waszak, 2011) and this, taken alone, does not provide evidence for the null hypothesis (Dienes, 2014). In studies where there is a reported difference in one component of binding but a failure to reject the null hypothesis for a difference in the other, it is likely that the data are merely insensitive and therefore uninformative. Therefore, there is little evidence to support a dual process model of intentional binding.

While there has been, to my knowledge, no direct test of cue combination in outcome binding, there is indirect evidence to support the theory that both action and outcome binding arise from cue combination. For example, the disruption of activity in the preSMA by transcranial magnetic stimulation reduces outcome binding (Moore, Ruge, Wenke, Rothwell & Haggard, 2010). The preSMA is thought to support motor intentions (for a review see Haggard, 2008) and therefore disruption of preSMA should decrease precision of action judgements. Outcome binding is also reduced when participants are led to incorrectly believe they did not cause an action (Desantis, Roussel & Waszak, 2011). In this case, an influence of motor intention information on the timing of an external event would be inappropriate, and this would be predicted to decrease the precision of action judgements. So, the existing empirical evidence is generally consistent with a cue combination model of both components of intentional binding. I will now consider the evidence for cue combination across the intentional binding studies presented in this thesis.

In Chapter V, data from an intentional binding study were analysed according to interactions predicted by a cue combination model of binding. Here I will report the same analyses applied to data from the intentional binding studies reported in Chapters III and IV. Descriptive statistics are reported for measures not reported in each chapter. For comparisons not reported in each chapter additional Bayes factors have been calculated using a half normal distribution as reported in Chapter V. Interaction graphs from Chapter V are reproduced here to facilitate comparison of the results of all three studies.

For these comparisons, variability was measured by the mean within-participant standard deviation of time judgements for the action and outcome events in the contingent condition. For between-group comparisons, in each case the prediction is that action judgement variability will be relatively low for the group theorised to have greater metacognitive access to first order intentions. Figure 1 shows the mean variability of time judgements for each event in meditators and controls. There was a sensitive interaction between group and type of event judged on within-participant SD, $F(1,14) = 12.78$, $p = .003$, $B_{H[0, 16]} = .182.05$. As reported in Chapter III, meditators showed less variable action judgements in the baseline condition than controls. However, there was no evidence for or against a difference in contingent action SD between meditators ($M = 51.0$ ms, $SD = 15.5$) and controls ($M = 81.4$ ms, $SD = 42.3$), $t(14) = 1.91$, $p = .077$, $B_{H[0, 16]} = 2.59$. Within-group, meditators did report less variable contingent action than outcome time judgements ($M = 77.7$ ms, $SD = 10.4$), $t(7) = 5.92$, $p = .001$, $B_{H[0, 16]} = 1744.56$ and there was no evidence for or against a difference in variability when measuring contingent action or outcome events ($M = 85.8$ ms, $SD = 45.1$) in controls, $t(7) = 1.00$, $p = .350$ $B_{H[0, 16]} = .66$.

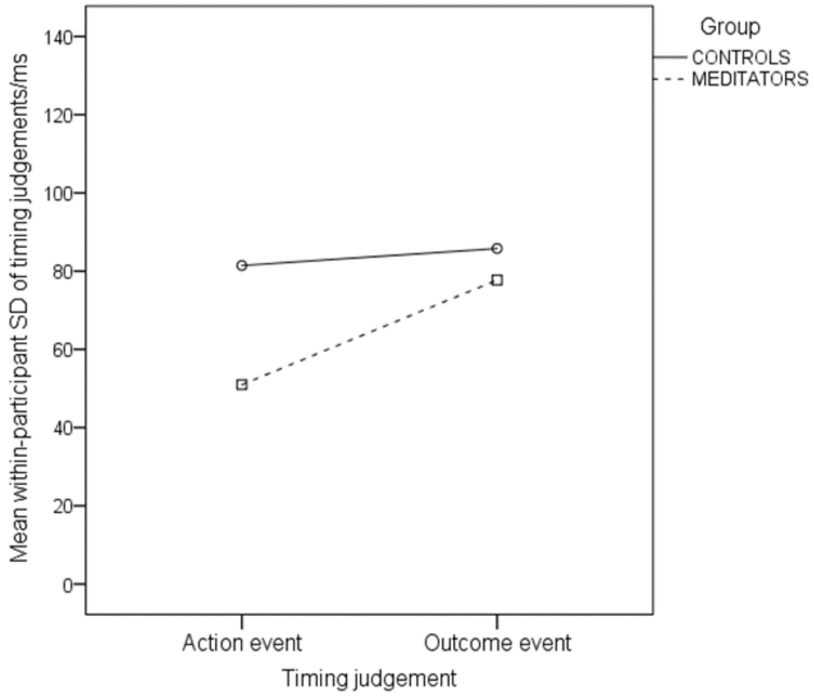

Figure 1. Interaction between group (meditators and controls) and judged event on within participant standard deviations of timing judgements in the contingent condition.

Figure 2 shows within-participant SD of judgements in high and medium hypnotisable participants following a post-hypnotic suggestion of involuntariness over motor action (Chapter IV) There was no sensitive evidence for or against an interaction, $F(1,22) = .317$, $p = .579$, $B_{H[0, 16]} = .48$, and the pattern of means is not quite consistent with predictions. While medium hypnotisables showed less variability of action timing report ($M = 62.5$, $SD = 6.8$) than highs ($M = 105.6$ ms, $SD = 34.4$), $t(9.5) = 3.90$, $p = .003$, $B_{H[0, 16]} = 1145.55$, their outcome timing judgement variability ($M = 79.7$, $SD = 31.2$) was also less variable than that of highs ($M = 130.6$, $SD = 48.1$), $t(22) = 3.15$, $p = .005$, $B_{H[0, 16]} = .8.18$. There was no sensitive evidence that medium hypnotisables were less variable when reporting action than outcome events, $t(13) = 2.11$, $p = .054$, $B_{H[0, 16]} = .2.78$, and the data were not sensitive as to whether or not there was a within-group difference in variability depending on event type for highs, $t(9) = 2.09$, $p = .067$, $B_{H[0, 16]} = .2.56$.

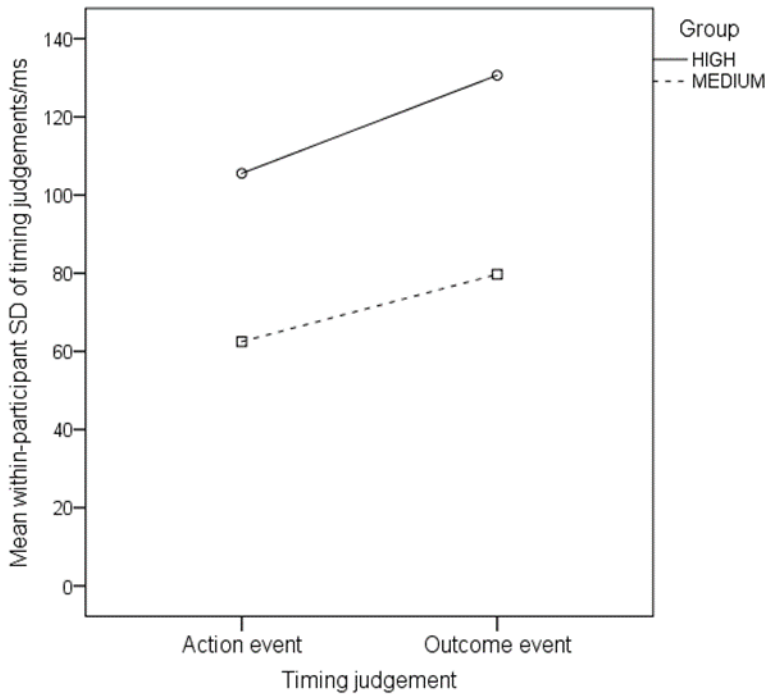

Figure 2. Interaction between group (high and medium hypnotisables) and judged event on within participant standard deviations of timing judgements in the contingent condition following a PHS suggestion of involuntariness.

Figure 3 shows the means for low and high hypnotisables and type of event for within-participant SD of timing judgements (reproduced from Chapter V). As reported in Chapter V, low hypnotisables reported less variable time judgements than controls and less variable judgements of action than of outcome timing. There was no evidence for or against a difference in variability depending on type of event in high hypnotisables.

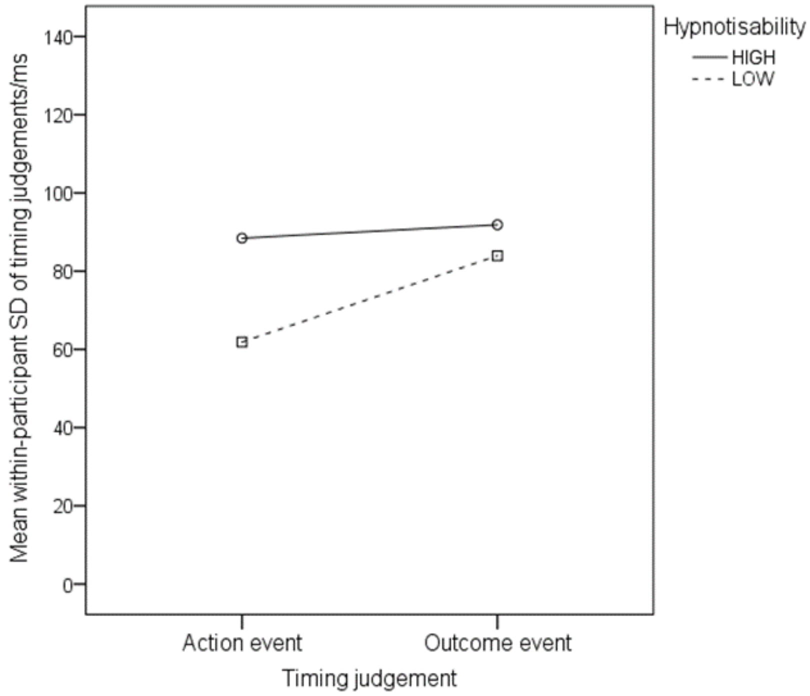

Figure 3. Interaction between group (high and low hypnotisables) and judged event on within participant standard deviations of timing judgements in the contingent condition.

In summary, the analyses of within-participant SD of timing judgements were in each case either sensitive in the direction predicted or simply insensitive (and therefore provide no evidence against predictions). The combined evidence is therefore consistent with the theory that the groups differ in availability of motor intention related information to higher cognitive processes. Interaction analyses from each study were entered into a Bayesian meta-analysis[1], which showed evidence for an interaction between group and within-participant SD of timing judgements in these studies, B = 184.61.

Assuming a cue combination mechanism, differences in the variability of timing judgements should be reflected in the components of binding; action binding should be of a relatively small magnitude and outcome binding of a relatively large magnitude when variability of action judgements is low and the opposite pattern should be seen when variability of action judgements is high. We can therefore predict a crossover

[1]Interactions between group and judged event type on within-participant SD of judgements were compared between each study to test whether or not it was appropriate to combine these results in a meta-analysis. *B*s were modelled using the predictions from Chapter V, but with a full normal as no directions for the differences were predicted. There was no evidence for a difference between the interactions of meditators and controls and of low and high hypnotisables (3.6 ms, *SE* = 11.93), $B_{H[0, 16]}$ = .62. The Bayes factor for the difference between the interactions of meditators and controls and of high and medium hypnotisables in PHS involuntariness was insensitive (10.42 ms, *SE* = 15.42), $B_{H[0, 16]}$ = .78. The Bayes factor for the difference between interactions of low and high hypnotisables and high and medium hypnotisables in PHS involuntariness was also insensitive, 10.8 ms (*SE* = 17.38), $B_{H[0, 16]}$ = .80. So there was no evidence for or against a difference in raw effect of interactions of group and type of binding on within participant SD in each study.

effect for the interaction between group and binding component in each case. Analysis of data from the study presented in Chapter III revealed a sensitive interaction between group and binding component, $F(1,14) = 4.90$, $p = .044$, $B_{H[0, 24]} = 4.17$. Figure 4 shows the mean shift from baseline for each event judged by meditators and controls. As reported in Chapter III, meditators outcome binding was greater than that of controls, but there was no evidence either way for a difference in action binding between groups. The magnitude of binding was, as predicted, smaller for action than outcome binding in meditators, $t(7) = 5.92$, $p = .001$, $B_{H[0, 24]} = 29832.86$ and there was sensitive evidence for a within-group difference of binding components in controls, $t(7) = 2.67$, $p = .032$, $B_{H[0, 24]} = 3.02$.

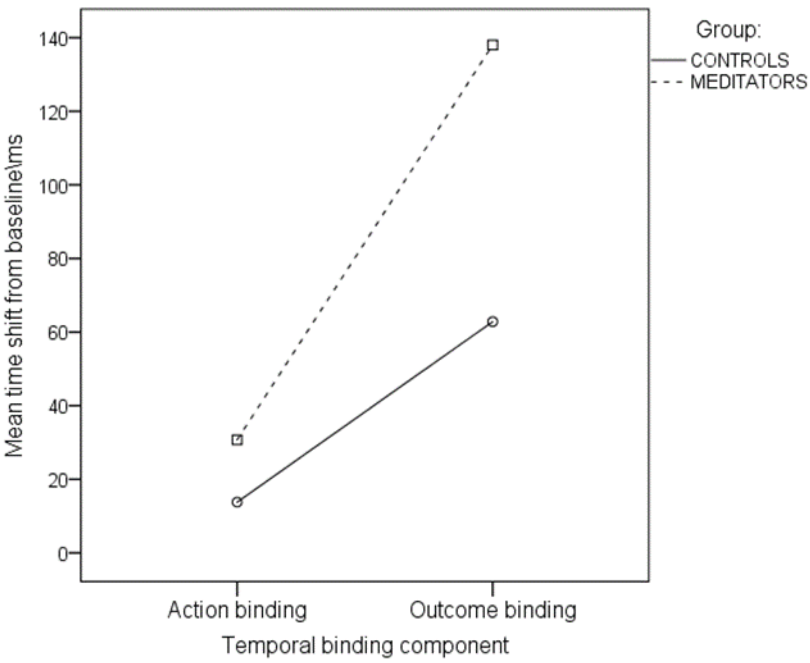

Figure 4. Interaction between group (meditators and controls) and type of binding.

The data from medium and high hypnotisables in the post-hypnotic involuntariness condition of the study reported in Chapter IV are presented in figure 5. There was no sensitive evidence for or against an interaction between group and binding component, $F(1,22) = 1.95$, $p = .18$, ($B_{H[0, 24]} = 1.77$). As reported in Chapter V, there was a difference in the predicted direction between groups in outcome binding, but no sensitive evidence for a difference in action binding. There was no evidence for or against a difference between action and outcome binding in high hypnotisables, $t(9) = 1.65$, $p = .134$, ($B_{H[0, 24]} = 1.70$), but there was evidence for a difference between action and outcome binding in the predicted direction for medium hypnotisables, $t(13) = 4.33$, $p = .001$, $B_{H[0, 24]} = 21.64$.

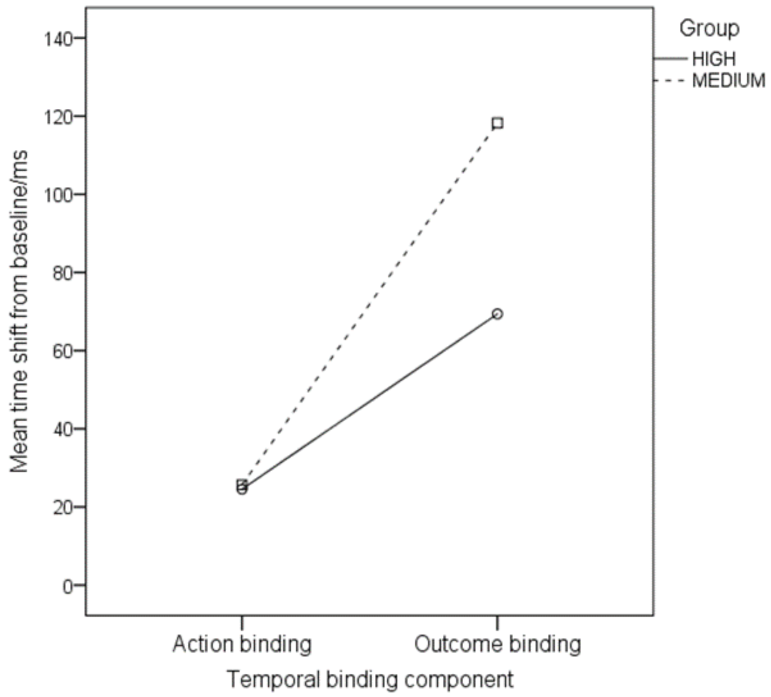

Figure 5. Interaction between group (high and medium hypnotisables) and judged event on type of binding following a PHS suggestion of involuntariness.

The predicted cross over interaction can be seen in the means of component binding across groups in the trait hypnotisability study (figure 6), but the evidence for an interaction was marginal. As described in Chapter V, the group with the least variable action judgements (low hypnotisables) showed a larger difference between action and outcome binding in the predicted direction, than the group with more variable action timing (high hypnotisables). There was evidence only for a difference in groups in action binding, as, while the pattern of means for outcome binding was in the predicted direction, there was no sensitive evidence for or against a group difference in this measure. Lows showed the predicted difference in action and outcome binding, but there was no evidence either way for a difference in magnitude of binding components in highs.

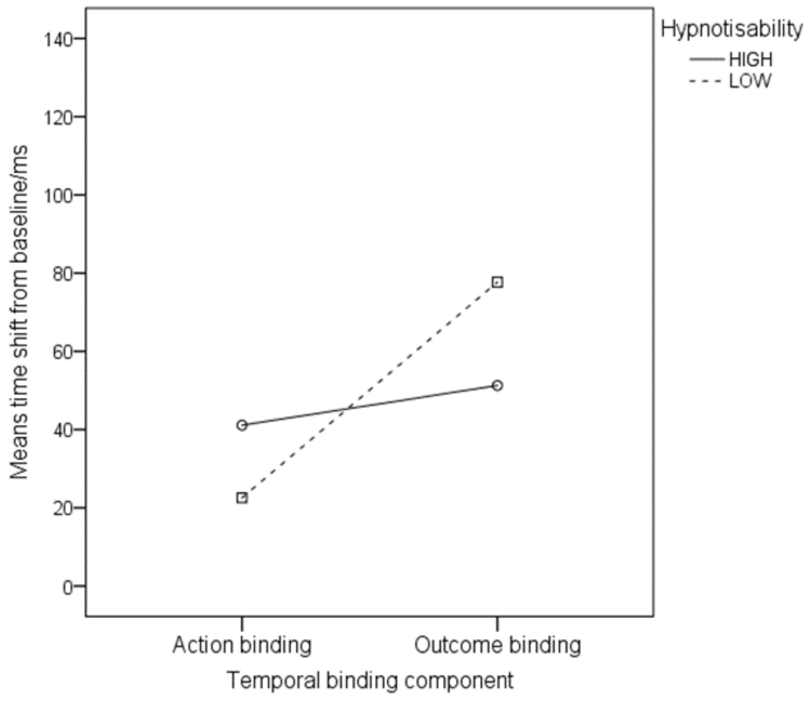

Figure 6. Interaction between group (high and low hypnotisables) and judged event on type of binding.

Taken together, these results are again a mixture of sensitive evidence consistent with predictions, and insensitive data. While only one binding component showed a sensitive group difference in each study, across studies there is evidence for the predicted differences in each component. A Bayesian meta-analysis[2] of these data revealed sensitive evidence for an interaction, B = 34.25.

So, together these studies are consistent with a cue combination mechanism of intentional binding. However, this evidence is indirect. Direct evidence for or against cue combination can be provided by manipulating the precision of the action and outcome cues directly. While such a test has provided evidence for cue combination in action binding (by adding varying levels of white noise to the outcome event; Wolpe, Haggard, Siebner & Rowe, 2013), there is, to my knowledge no published work directly testing the predictions of cue combination for outcome binding. This could be achieved by manipulating the precision of action judgements directly in future experiments (e.g., by altering the available sensory feedback regarding the timing of action).

[2]Interactions between group and type of binding on time shift from baseline were compared to test before combining these results in a meta-analysis. *B*s were modelled using the predictions from Chapter V with a full normal. There was no evidence for a difference between the interactions of meditators and controls and of low and high hypnotisables (13.4 ms, SE = 36.3), $B_{H[0, 24]}$ = .85. The B for the difference between the interactions of meditators and controls and of high and medium hypnotisables in PHS involuntariness was insensitive (8.4 ms, SE = 44.3), $B_{H[0, 24]}$ = .88. The B for the difference between interactions of low and high hypnotisables and high and medium hypnotisables in PHS involuntariness was also insensitive, 5 ms (SE = 43.4), $B_{H[0, 24]}$ = .88. So there was no evidence for or against a difference in raw effect of interactions of group and type of binding on time shift from baseline.

Consideration should be given to an alternative interpretation of the intentional binding results reported in Chapter IV. Hypnotic responding may require attention and therefore consume cognitive resources Bryant & McConkey (1990). For example, maintaining an experience of hypnotic blindness reduces performance on a decision task (Wyzenbeek & Bryant, 2011). Higher action and outcome timing variability was seen in highs compared mediums in the PHS involuntariness condition, and this might be attributable to a decrease in attention to the task. However, we should expect reduced attention to the task to result in increased binding (Haggard & Cole, 2007), and here outcome binding decreased with increasing variability of action judgement.

I will now consider some implications of a cue combination model of intentional binding for the interpretation of binding as an implicit measure of the sense of agency. Much of the intentional binding literature reports an overall binding measure rather than the individual action and binding components. Indeed, when binding is measured by direct interval estimation (Engbert, Wohlschläger & Haggard, 2008) or by delay estimation (e.g., Kawabe, Roseboom & Nishida, 2013; Wen, Yamashita & Asama, 2017), identifying the relative movement of the individual shifts is not possible. However, the exclusive use of an overall binding measure is problematic as a particular magnitude of overall binding could be informed by many patterns of results, depending on the relative weighting of each cue; action binding might be high while outcome binding is low, or vice versa. In addition, while our focus here has been on the availability of information regarding the action event, differences in binding could also arise from varying availability of information regarding the outcome event (e.g., Wolpe, Haggard, Siebner & Rowe, 2013). Therefore, future studies should identify individual components of binding and the variability of timing of each event whenever possible.

A related issue is that, according to cue integration models of the sense of agency, the relationship between individual shifts in the components of intentional binding and sense of agency is not straightforward. For example, having relatively weak outcome binding does not necessarily mean that high hypnotisables have a stronger sense of agency in everyday life, because when information from one source is weak, other information will be weighted more highly in generating a sense of agency (Moore & Fletcher, 2012). Therefore, highs may have a strong sense of agency, but one which relies more on external cues and internal contextual cues than on motor intentions.

I will now discuss some issues relating to the temporal binding of events related to inferred causality. Intentional binding is established as a measure of sense of agency to the degree that differences in overall intentional binding are often referred to directly as differences in sense of agency (e.g., Caspar, Christensen, Cleeremans & Haggard 2016; Engbert; Kawabe, Roseboom & Nishida, 2013; Obhi, Swiderski & Brubacher, 2012; Wohlschläger & Haggard 2008). However, binding occurs in the absence of intentions when a causal relationship between action and outcome is inferred (Buehner, 2012; note that Cravo, Claessens & Baldo, 2009, who report no evidence for binding in the absence of intentions, do not report evidence for no binding in the absence of intentions). Hughes, Desantis & Waszak (2012) and Buehner (2015) argue that the influence of causality is rarely controlled for in intentional binding studies. For example, in the first report of intentional binding (Haggard, Clark & Kalogeras, 2002) voluntary action was contrasted with an involuntary condition in which movement was triggered by TMS stimulation of motor cortex. However, the TMS condition differed both in voluntariness of action and in causality; the action was a twitch rather than a button press and the outcome was time-locked to the moment of TMS activation.

Therefore, the difference in binding between conditions is likely to be at least partially attributable to a change in the inferred causal relationship between action and outcome.

Consistent with Buehner (2015), in Chapter IV, outcome binding occurred in the passive movement condition, during which information related to motor intentions was unavailable for timing judgements. This binding in the passive condition may be due to an inferred causal relationship and, therefore the difference between binding in the passive and voluntary conditions might be taken to reflect the magnitude of binding that is due to intention, over and above that due to causal inferences. When comparing a voluntary and a passive movement, the differences between conditions may not be limited to the presence or absence of intentions (e.g., the speed of the button press or the nature of proprioceptive information may also differ between intended and passive action). However, potentially confounding differences between PHS involuntariness and voluntary action conditions in Chapter IV would be limited, so the comparison between passive binding and binding in post-hypnotic involuntariness may provide a relatively pure measure of intentional binding.

So, intentional binding involves beliefs regarding a causal relationship between actions and outcomes (Buehner & Humphreys, 2009) and prior beliefs about the environment are used to disambiguate sensory information (Ernst & Bulthoff, 2004) Therefore, if binding is driven by a cue combination mechanism, prior beliefs about causality are likely to be influential. The classic intentional binding task involves pressing a button or switch and triggering an outcome. In the developed world we have extensive experience of a similar situation every time we press a light switch or change the channel on a TV, and in the majority of situations the outcome occurs so rapidly following the action that it is almost instantaneous. It is likely that strong prior beliefs that button pressing triggering an instantaneous event develop over repeated experience of such events. The simplest model for intentional binding is therefore a cue combination model with a causal prior arising from the experience of contingency of button presses and outcomes during ontogeny. Applicable models exist for binding across other modalities (e.g. Roach, Heron & McGraw, 2006), and could be explored using data from an intentional binding study in which the variability of action or outcome judgements is manipulated.

I will now briefly consider how these results presented in this thesis relate to arguments regarding the relationship between implicit and explicit measures of sense of agency. The evidence for whether or not explicit judgements of agency track implicit judgements is mixed (Barlas & Obhi, 2014; Borhani, Beck & Haggard, 2017; Dewey & Knoblich, 2014; Ebert & Wegner, 2010; Moore, Middleton, Haggard and Fletcher, 2012). In Chapter IV, a reduction in outcome binding accompanied verbal reports of a considerable reduction in the experience of agency over an action-outcome following a post-hypnotic suggestion of involuntariness. This is consistent with accounts that argue for a relationship between implicit measures and explicit judgements of agency. However, these results do not provide evidence that implicit and explicit measures cannot dissociate; for example, in this case motor intentions may provide information relevant both to intentional binding and explicit sense of agency, but the processes supporting each may be entirely distinct. Future studies testing hypnotic involuntariness in other implicit measures (e.g., sensory attenuation) might further inform theories of the relationship between implicit and explicit measures of sense of agency.

I will now address issues relating to the other measure employed in these studies, Libet al's (2013) judgements of the timing of an intention to move. Dominik et al (2017) report that W judgements are shifted earlier in time if they follow M judgements. The data for the study reported in Chapter II also show later average W time when M judgements were also recorded (*M* = -143.7 ms, *SD* = 159.0; Study 3) than when W judgements alone were recorded (*M* = -63.4, *SD* = 12.8), $t(36.61) = 2.45$, $p = .019$, $B_{H[0, 115]} = 8.82$ (*B* modelled as in Chapter II). Dominik et al (2017) argue that in the absence of experience of M judgements, participants may interpret W judgements to be the timing of action occurrence, and that when M judgements are present, W time is at least partly inferred from M judgement timing (see also Gomes, 1988; Banks & Isham; 2009). However, Dominik et al (2017) do not report evidence for there being no difference between W and M timings in M judgement naïve participants, and in Chapter II a Bayesian meta-analysis revealed that for groups who differed in W judgements there was evidence for no difference in M judgements. Additionally, in Chapter II a negative relationship between hypnotisability and the distance between W and M judgements was found. So, how can the influence of M on W timing in Study 3 of Chapter II be explained? It is possible that only some M judgement-naïve participants confuse W judgements with the timing of action, leading to later group average judgement time. Alternatively, experience with M judgements might help participants distinguish between information related to action and that related to intention, so that on average W timings are later when M judgements are taken.

I turn now to consideration of a potential confound for the results presented here relating to both intentional binding and W judgements. Although the results here have been interpreted as evidence for differences in metacognition of intentions, there is a more prosaic explanation which cannot be ruled out; no attempt was made to control for the speed of participants' movement in any of the cognitive tasks. A relatively slow, deliberate action might be expected to result in less variability of action timing judgements and consequently any differences in binding predicted by a cue combination mechanism. A slower button pressing speed would also result in an earlier W time, as the time of action is recorded at the point of contact of the button and its sensor and not at the time of the initiation of movement, leaving more of a gap between action initiation and action completion for slow actions. Indeed, Buddhist mindfulness practice encourages slow, deliberate movement (Hanh, 1976). Hypnotisability, on the other hand may be positively correlated with motor impulsivity (Ludwig et al, 2013), and a tendency toward motor impulsivity could plausibly result in quicker and less deliberate button pressing. Therefore, future studies should control for this possible confound by measuring the speed of action in button pressing tasks.

The same criticism could apply to the correlation between motor impulsivity and W judgements reported in Caspar & Cleeremans (2015). These results are attributed to individual differences in the time that decisions occur, but they could alternatively arise from individual differences in metacognition of intentions. If so, it is possible that the relationship between motor impulsivity and W timing at least partly reflects the varying hypnotisability of participants. Future studies could explore this possible link between hypnotisability and motor impulsivity by testing for correlations with hypnotisability and motor impulsivity measures away from the hypnotic context.

Disorders of agency

I will now consider possible parallels between the results presented here and reports of intentional binding and W judgements in neurological and psychiatric conditions which are related to disorders in the sense of agency. Clinical groups with disorders of agency show differences from controls in direct measures of components of binding in a manner consistent with a cue combination mechanism. Wolpe et al (2013) report a relationship between high action binding and grey matter volume changes in preSMA in corticobasal syndrome. As corticobasal syndrome involves disorders of the sense of agency and the preSMA is considered to support motor intention-related information, relatively high action binding in corticobasal syndrome (as in high hypnotisables; Chapter IV) may arise from low precision of action event timing judgements.

Schizophrenia commonly involves disruptions to the sense of agency (Frith, 2012; Jeannerod, 2009), and when performing an intentional binding task in which the predictability of an outcome is manipulated (Moore & Haggard, 2008), schizophrenic patients have been shown to rely more on external, retrospective cues than on internal predictive signals (e.g., motor intentions) compared to controls (Voss et al 2010). In the same study, greater action binding (as reported in Chapter V in trait hypnotisability) was seen in schizophrenic patients than in controls. If both schizophrenia and hypnotisability are related to relatively low access to first order information about motor intentions, we should expect to see a similar pattern in highs. This possibility could be tested by applying Moore & Haggard's (2008) method for testing relative reliance on internal and external cues to hypnotisable groups.

In functional motor disorders (FMDs), patients present with symptoms of neurological disease (e.g., Parkinsonian tremors or epileptic fits). However, in FMDs, neurobiological evidence is inconsistent with these conditions and motor actions show signs typically associated with voluntary movements (e.g. distractibility). Hallett (2012) has argued that, to explain this "there must be a brain mechanism that allows voluntary movement to occur but to be experienced subjectively as involuntary." The cold control theory of hypnosis may provide such an explanatory mechanism, in that FMDs may be a case of malfunctioning cold control. The hypnotic responding is voluntary (e.g., Hilgard, 1963; Orne, 1972), whereas in FMDs the production of an experience of involuntariness over voluntary action is itself involuntary. The key difference would therefore be that while hypnosis involves the voluntarily inaccurate metacognition of intentions, in FMD, this mechanism is activated involuntarily. FMDs have been associated with hypnosis since the 19th century, but while there is evidence that FMD patients show higher response to hypnotic suggestion (Roelofs et al, 2010), there is little direct evidence to link the two phenomena. However, there are patterns of results in cognitive tasks in FMD patients which mirror those reported for hypnotisables here.

In an intentional binding task, outcome binding is reduced in FMD patients compared to controls (Kranick et al, 2013), and this is consistent with FMD patients, like the high hypnotisables reported in Chapter V, having less reliable information about their action. FMD patients also report relatively late awareness of an intention to move (Edwards et al, 2011), as reported for high hypnotisables in Chapter II. Future work could further investigate the relationship between FMD and metacognition of intentions. Cold control theory could be therefore useful in suggesting previously unexplored possible treatments. For example, specific training in metacognition of intentions through mindfulness practice might decrease FMD symptoms by reducing the ability to form and maintain inaccurate HOTs of intending.

According to HOT theory there should be two distinct routes to reductions in motor intention related information. The first involves a change in HOTs directed at intact first order representations, such as may occur in hypnotisability (and perhaps in FMDs). Disruption of information relevant to motor intentions might therefore be induced by TMS of the dlPFC. Indeed, there is evidence (Dienes & Hutton, 2013). Alternatively, a reduction in the availability of motor intention-related information to timing judgements could be the result of disruptions to first order representations, which may be supported by more caudal areas which include the preSMA. This is most likely to be the case in corticobasal syndrome, which is associated with alterations in the preSMA.

Conclusion

The results presented in this thesis are consistent with the theory that hypnosis and mindfulness meditation are related to metacognition of intentions in opposing ways; the practice of mindfulness meditation may develop metacognition of intentions, while trait differences in the ability to respond to hypnotic suggestions may reflect differences in the availability of first order intentions to higher order thoughts (HOTs). Mindfulness meditators report an earlier awareness of an intention to move and less variable judgements when timing motor actions than non-meditators. Low hypnotisables report an earlier awareness of an intention to move and less variable motor action timing judgements than high hypnotisables. These results may reflect differences in higher order access to motor-intention related information. Explicit reports of the experience of involuntariness in hypnotic responding are reflected in a reduction in outcome binding, which may reflect a reduction in the precision of motor action timing judgements when motor intention-related information is afforded relatively low weighting in HOTs of intending. Mindfulness meditators report relatively strong outcome binding compared to non-meditators. High hypnotisables report relatively strong action binding compared to low hypnotisables. These results are consistent with a cue combination mechanism underlying both action and outcome binding. The Sussex-Waterloo Scale of Hypnotisability (SWASH) is a valid time-efficient measure of hypnotisability which may increase the viability of hypnosis research for the wider research community.

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Supplemental material for Chapter II

Study 2: correlations with individual measures of hypnotisability.

There was no sensitive evidence for whether or not there was a correlation between W judgements and FFMQ-SF score, $r(34)= -.231$, $p = .189$, $B_{H(0, .30)} = 1.75$.[1] There was a positive correlation between subjective hypnosis rating and Mean W judgement ($M = -75.0$ ms, $SD = 84.5$ ms) , $r(34)= .44$, $p = .009$, $B_{H(0, .30)} = 15.60$. Although between subjective and objective hypnosis ratings correlated, $r(34)= .69$, $p< .001$, $B_{H(0, .82)}= 16439.52$, there was no sensitive evidence for whether or not objective hypnosis rating ($M = 2.0$, $SD = 1.4$) correlated with W, $r(34)= .19$, $p > .250$, $B_{H(0, .30)} = 1.30$.

There was a negative correlation between subjective hypnosis rating ($M = 9.5$, $SD = 4.6$) and FFMQ score ($M = 78.7$, $SD = 10.1$), $r(34)= -.45$, $p = .008$, $B_{H(0, .30)} = 21.33$. The correlation between FFMQ-SF score and objective hypnosis rating was $r(34)= -.32$, $p = .063$. $B_{H(0, .30)} = 3.64$.

Study 3: correlations with individual measures of hypnotisability

The correlation between objective hypnosis rating ($M = 1.6$, $SD = 1.2$) and W ($M = -143.7$, $SD = 159.0$) was Spearman's ρ (28) = .35, $p = .071$, $B_{H(0, .30)} = 3.64$. The relationship between objective hypnosis rating and M/W distance ($M = 117.2$, $SD = 120.2$) was Spearman's ρ (28)= -.36, $p = .060$, $B_{H(0, .30)} = 4.16$.

There was no sensitive evidence for whether or not there was a correlation between subjective hypnosis rating ($M = 8.6$, $SD = 4.8$) and W, Spearman's ρ (28)= .239, $p = .220$, $B_{H(0, .30)} = 1.66$ nor for a correlation between M/W distance and subjective hypnosis rating, Spearman's ρ (28)= .-.297, p = .125, $B_{H(0, .30)} = 2.47$.

The evidence was not sensitive for whether or not there were correlations between FFMQ-SF and subjective hypnosis rating, Spearman's ρ (26)= -.233, p = .253, $B_{H(0, .30)}$ = 1.51, or objective hypnosis rating, Spearman's ρ (26)= -.029, p = .890, $B_{H(0, .30)}$ = .61.

Supplemental material for Chapter III

Jo et al (2014) reported a non-significant difference in intentional binding between mindfulness meditators and age-matched controls. Meditators had similar levels of experience in the two studies. Jo et al (2014) reported slightly lower mean continuous meditation experience of 10.1 years (*SD* = 6.4) than in the current study (14.6 years (*SD* = 11.6)). Jo et al (2014) did not report the range of meditation experience, but in the current study experience ranged from 3-40 years. Both studies employed a cut-off of three years of continuous meditation experience. We will now consider the statistical evidence. Although the first study had a larger *n* (19 age-matched pairs), we report smaller SDs for all conditions. For example, the overall binding measure reported in in Jo et al (2014) has a SD of 170.4 ms for meditators and 105.0 ms for controls (98.9 ms and 62.6 ms respectively in the current study)**.** The large SDs (and consequently large standard errors) mean that Jo et al's study would have required more participants to provide evidence for a difference (by null hypothesis significance testing) or for evidence of no difference (by Bayesian analysis). It should be emphasised that although Jo et al found no significant difference between meditators and non-meditators in intentional binding, a failure to reject the null hypothesis at a given alpha level does not provide evidence for the null hypothesis. However, Bayes factors can be employed to test evidence for the null hypothesis (Dienes, 2014, Wagenmakers et al, 2016, Dienes, 2016), and in fact a meta-analysis of the results of the two studies provides sensitive evidence for an increase in overall binding and outcome binding.

In Jo et al (2014) non-meditators had total binding of 79 ms. Thus a difference between groups of about half this, or 40 ms, could reasonably be expected (Kranick et al, 2013). A Bayes factor, *B* can be used to assess the strength of evidence for the alternative hypothesis, H1, over the null hypothesis, H0, (Dienes, 2014). A B of less than 1/3 can be taken as substantial evidence for H0 over H1; between 1/3 and 3 as non-evidential or only weakly evidential; and of greater than 3 as substantial evidence for H1 over H0. For overall binding, $B_{H(0, 40)=}$ 2.56, which is weak evidence in favour of a difference between meditators and non-meditators. For outcome binding alone, $B_{H(0, 45)}$ = .54; and for action binding, $B_{H(0, 5.5)=}$ 1.05, in both cases indicating insensitive evidence and no conclusions follow about the difference between meditators and non-meditators for the separate components.

Welch's unpaired t-tests were used to compare binding measures across studies. The mean difference on action binding (-28.7 ms, SE = 33.1) was insensitive $t(24) = .195$, $p = .369$, $B_{H(0, 9)}$= .99, as was the mean difference on outcome binding (39.3, SE = 35.7), $t(23) = 1.10$, $p = .282$, $B_{H(0, 32)}$ = .98 and overall binding (-68 ms, SE = 52.5), $t(22) = 1.30$, $p = .208$, $B_{H(0, 40)}$ = 1.08. Therefore, there is no sensitive evidence for a difference in the findings of the two studies.

A fixed-effects meta-analysis was conducted on binding measures in meditators and controls reported here and in Jo, Hinterberger and Schmidt (2014) For overall binding, the mean difference = 63.2 ms, [2.9, 123.4], $B_{H(0, 40)}$ = 4.36, supporting the group difference in overall binding. For outcome binding, the mean difference = 50.4 ms, [6.2, 94.7], $B_{H(0, 32)}$ = 5.90, providing support for a difference in outcome binding. The result for action binding was inconclusive, mean difference = 15.6 ms, [-15.9, 47.2], $B_{H(0, 9)}$ = 1.34.

Supplemental material for Chapter IV

Total binding

Table S1 shows the total binding measure and standard deviation of baseline action judgements in each condition for the high and medium hypnotisable groups. Table S2 shows *p* values, Bayes factors, 95% confidence intervals and effect size for post-hoc comparisons for each main effect for these groups.

There was a significant main effect of condition on total binding, $F(2, 44) = 10.31$, $p < .001$, $\eta^2p = .319$, but no significant main effect of hypnotisability, $F(1, 22) = .190$, $p > .250$, $\eta^2p = .009$. The interaction between condition and group on total binding was also significant, $F(2, 44) = 3.77$, $p = .031$, $\eta^2p = .15$ The theory that hypnotic response is experienced as passive predicts two key partial interactions. As predicted, there was an interaction between group and voluntary vs post-hypnotic conditions on total binding, $F(1, 22) = 6.82$, $p = .016$, $B_{H(0, 72)} = 13.89$, $\eta^2p = .237$. There was no evidence one way or the other for a predicted interaction between passive and post-hypnotic conditions, $F(1,22) = 1.16$, $p > .250$, $B_{H(0, 72)} = 1.12$, $\eta^2p = .050$. Finally there was no sensitive evidence for an interaction between group and voluntary vs passive conditions on total binding, $F(1,22) = 4.04$, $p = .057$, $B_{N(0, 72)} = 1.80$, $\eta^2p = .16$. Simple effects analyses showed that for the high hypnotisable group there was a significant main effect of agency condition on total binding $F_{corrected}(1.09, 9.79) = 7.33$, $p = .021$, $\eta^2p = .45$. Compared to the voluntary condition, total binding was lower in both the passive action and post-hypnotic conditions in this group. There was also a significant main effect of agency on total binding in the medium hypnotisable group, $F(2, 24) = 5.68$, $p = .009$, $\eta^2p = .31$. Total binding was greater in the voluntary and post-hypnotic conditions than in the passive condition and there was evidence in this combined measure for no difference between voluntary and post-hypnotic action in medium hypnotisables.

Standard deviation of baseline action judgements

There was a significant main effect of condition on baseline action judgement SD, $F(2, 44) = 3.77$, $p = .031$, $\eta^2p = .15$, and also a significant main effect of group, , $F(1, 22) = 14.59$, $p = .001$, $\eta^2p = .399$. There was a significant interaction between group and condition on this measure, $F(2, 44) = 7.80$, $p = .001$, $\eta^2p = .262$, indicating that highly hypnotisable participants showed more variability in in their baseline action judgements during the post-hypnotic condition than in the voluntary condition. There was an interaction between group and voluntary vs post-hypnotic conditions on baseline action SD, $F(1, 22) = 9.64$, $p = .005$, $B_{H(0, 35)} = 44.14$, $\eta^2p = .305$, and between group and passive and post-hypnotic conditions, $F(1,22) = 4.74$, p =. 040, $B_{H(0, 35)} = 5.57$, $\eta^2p = .18$. Finally there no evidence either way for an interaction between group and voluntary vs passive conditions, $F(1,22) = 1.76$, $p = .198$, $B_{N(0, 35)} = 0.84$, $\eta^2p = .07$. Analysis of simple effects showed that, for the high hypnotisable group, there was a significant main effect of condition on judgement SD in the baseline action condition, $F(2, 18) = .5.44$, p = .014, $\eta^2p = .38$. Baseline action judgement SD was higher in the post-hypnotic condition than in the voluntary condition. For the medium hypnotisable group there was no significant main effect of agency on SD in the baseline action condition, $F(2, 24) = 3.76$, p = .074, $\eta^2p = .18$. However, Bayesian analysis showed that baseline action SD was higher in the passive condition than in the voluntary condition. There was sensitive evidence for no difference in solo action baseline SD between the voluntary and post-hypnotic conditions.

Table S1: Total binding and mean SD of baseline action judgements for the high and medium hypnotisable groups in the three experimental conditions

Group (hypnotisability)		Condition: Voluntary	Condition: Post-hypnotic involuntariness	Condition: Passive
High				
	Total binding	158.6 (52.1)	94.0 (72.6)	73.7 (64.2)
	SD of baseline action judgements	80.7 (38.0)	133.1 (60.1)	113.5 (46.6)
Medium				
	Total binding	130.2 (70.3)	143.0 (76.1)	87.4 (96.0)
	SD of baseline action judgements	62.0 (14.1)	65.0 (13.8)	74.6 (19.5)

Mean times are given in ms (SD).

Table S2: Post-hoc comparisons of total binding and solo action judgment SD between each condition in the high and medium hypnotisable groups.

Group (hypnotisability)		Comparison		
		Voluntary action vs passive action	Voluntary action vs Post-hypnotic suggestion	Passive action vs post-hypnotic suggestion
High				
	Total binding	$p < .001$* $B_{H(0, 79)} = 1.24 \times 10^{16}$** [67.5, 102.4] $dz = 2.17$	$p = .034$* $B_{H(0, 79)} = 4.04$** [5.9, 123.5] $dz = 0.66$	$p > .250$ $B_{H(0, 79)} = .66$ [- 87.2, 46.8] $dz = 0.21$
	SD of baseline action judgements	$p = .079$ $B_{H(0, 40)} = 2.34$ [-70.4, 4.72] $dz = 0.59$	$p = .017$* $B_{H(0, 40)} = 7.63$** [-92.9, -11.9] $dz = 0.83$	$p = .176$ $B_{H(0, 40)} = 1.19$ [-49.7, 10.5] $dz = 0.45$
Medium				
	Total binding	$p = .024$* $B_{H(0, 71.5)} = 5.76$** [6.6, 79.0] $dz = .64$	$p > .250$ $B_{H(0, 71.5)} = 0.17$ [-49.6, 23.8] $dz = .20$	$p = .009$* $B_{H(0, 71.5)} = 17.90$** [-94.8, -16.5] $dz = .75$
	SD of baseline action judgements	$p = .033$* $B_{H(0, 31)} = 3.35$** [-24.0, -1.2] $dz = .60$	$p > .250$ $B_{H(0, 31)} = .28$** [-12.8, 6.9] $dz = .17$	$p = .159$ $B_{H(0, 30.5)} = .96$ [-4.3, 23.6] $dz = 0.39$

** Significant at the .05 level. ** Sensitive B (> 3 or < 1/3). Brackets contain 95% CIs*

Results of analyses with all highly hypnotisable participants included.

The results for all highly hypnotisable participants for which we have complete data (regardless of whether they were able to sustain an experience of involuntariness) are shown in table S3 and S4.

Table S3: Mean binding for all highly hypnotisable participants in the three experimental conditions

	Condition		
	Voluntary	Post-hypnotic involuntariness	Passive
Total binding	159.9 (66.3)	103.2 (94.0)	85.5 (90.7)
Action binding	21.6 (23.9)	15.8 (51.5)	9.3 (52.4)
Tone binding	-138.3 (68.4)	-87.4 (85.3)	-76.2 (117.8)

Mean times are given in ms (SD).

Table S4: Post-hoc comparisons between each condition in all highly hypnotisable participants.

	Comparison		
	Voluntary action vs passive action	Voluntary action vs Post-hypnotic suggestion	Passive action vs post-hypnotic suggestion
Total binding	p =.004* $B_{H(0, 75)}$ = 48.02** [27.8, 121.0] dz = 3.42	p = .070 $B_{H(0, 75)}$ = 2.85 [-5.18, 118.5] dz = 0.51	p >.250 $B_{H(0, 75)}$ = .59 [-62.8, 27.4] dz = 0.22
Tone binding	p = .041* $B_{H(0, 65.5)}$ = 4.49** [-121.3, -2.8] dz = 0.58	p = .057 $B_{H(0, 65.5)}$ = 3.33** [-103.3, 1.7] dz = 0.54	p > .250 $B_{H\ 0, 65.5)}$ = .54 [-44.3, 62.8] dz = 0.11
Action binding	p > .250 $B_{H(0, 4.5)}$ = 1.26 [-11.8, 36.5] dz = 0.28	p >.250 $B_{H(0, 4.5)}$ = 1.07 [-18.5, 30.2] dz = 0.13	p > .250 $B_{H(0, 4.5)}$ = 1.04 [-32.3, 45.3] dz = 0.09

** Significant at the .05 level. ** Sensitive B (> 3 or < 1/3). Brackets show 95% Cis*